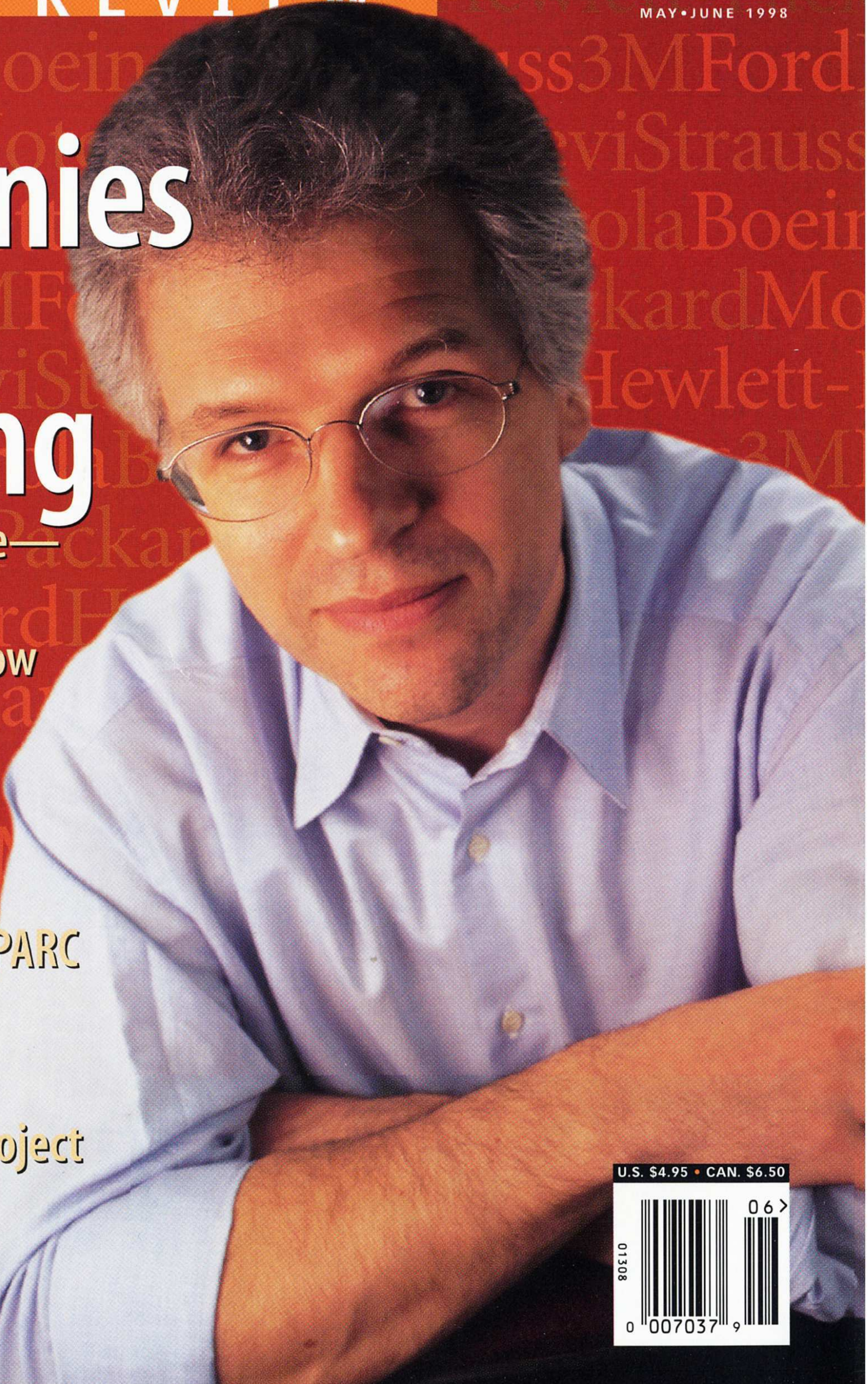
MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

MAY • JUNE 1998

The Companies Left Standing

They thrive on change—productivity expert Richard Lester tells how



PLUS

New Materials at Lightning Speed

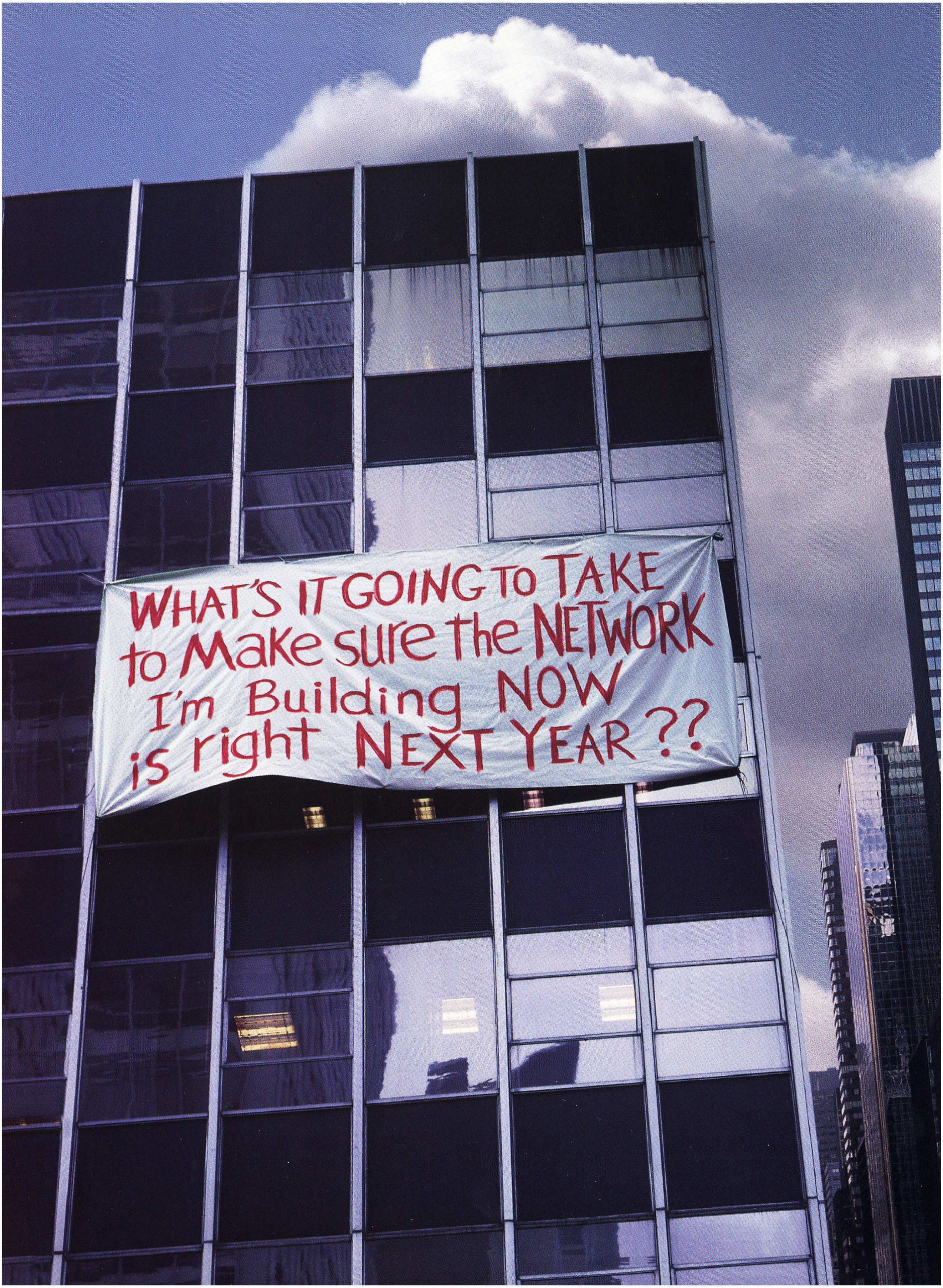
Innovation at Xerox PARC

Up Close: The Father of the Internet

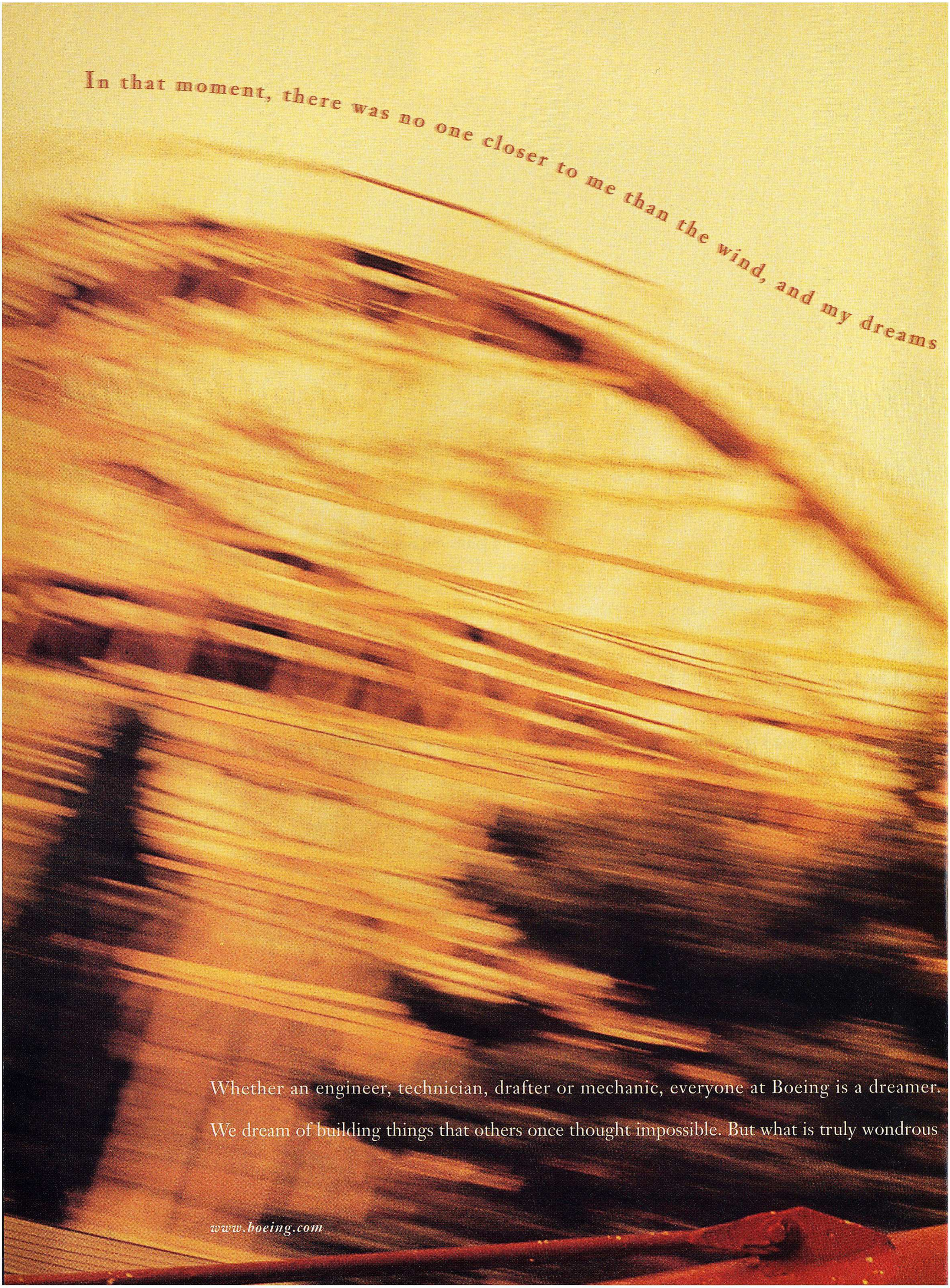
The Next Genome Project

Boston's High-Tech "Big Dig"

U.S. $4.95 • CAN. $6.50


WHAT'S IT GOING TO TAKE
to Make sure the NETWORK
I'm Building NOW
is right NEXT YEAR??

KNOW-HOW What's it going to take to get the bandwidth you need (where & when & as fast as you need it)? To handle wireless communications as easily as wired? To get data as reliable as voice? (?????) It's going to take people. Technology. Experience. And the ability to deliver. We've built, and continue to build, the most powerful networks on earth. We've got the largest service force in the industry (already we service more networks than anyone on the planet). And we've got the brains of Bell Labs behind us. This is the kind of combined arsenal it's going to take to make sure the network you start building now is strong enough to be your network down the road. **We make the things that make communications work.™**


In that moment, there was no one closer to me than the wind, and my dreams
Whether an engineer, technician, drafter or mechanic, everyone at Boeing is a dreamer.
We dream of building things that others once thought impossible. But what is truly wondrous
www.boeing.com


of building flying machines took wing.
is that we never stop at just dreaming. Send resumes to The Boeing Company, P.O. Box 3707, M/S 6H-RC, C-MR58, Seattle, WA 98124. Boeing is an equal opportunity employer supporting diversity in the workplace.
BOEING

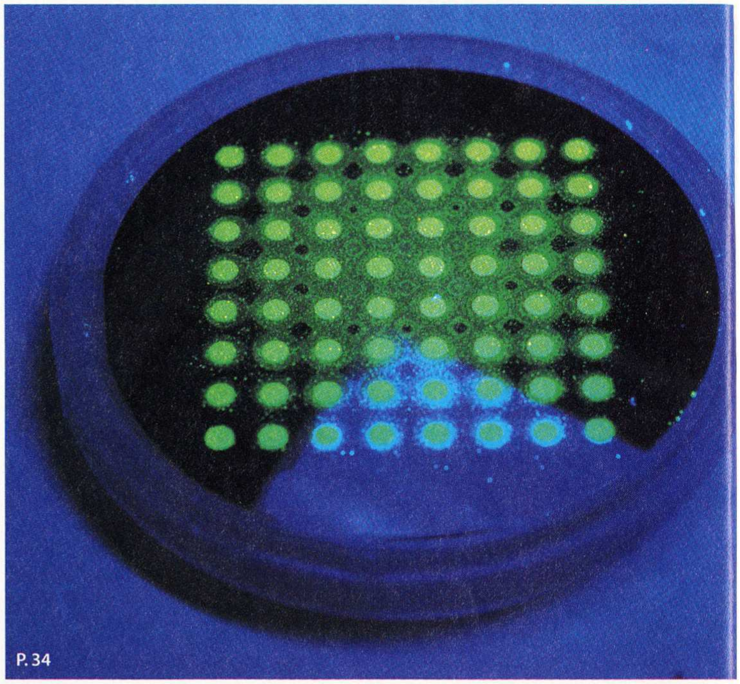
CONTENTS

TECHNOLOGY REVIEW *May/June 1998*

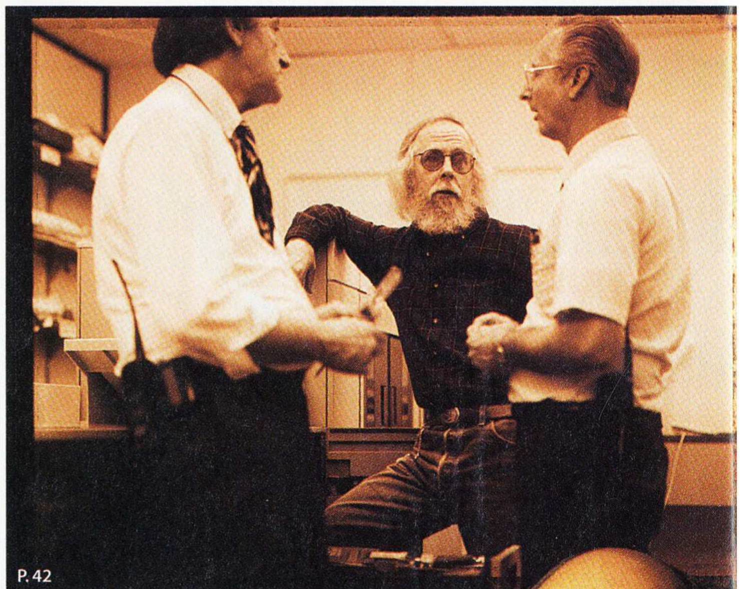
VOLUME 101, NO.3

Features

Cover Photograph by Brian Smale

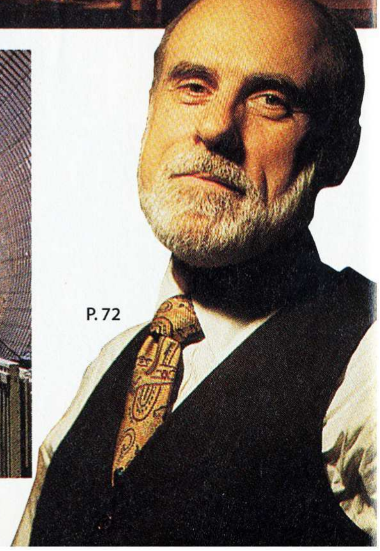


P.34



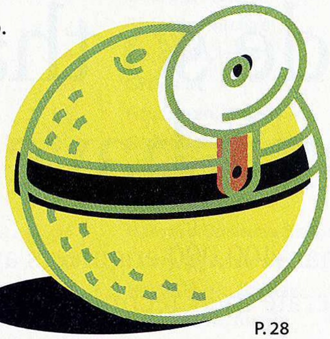
P.42

P.66



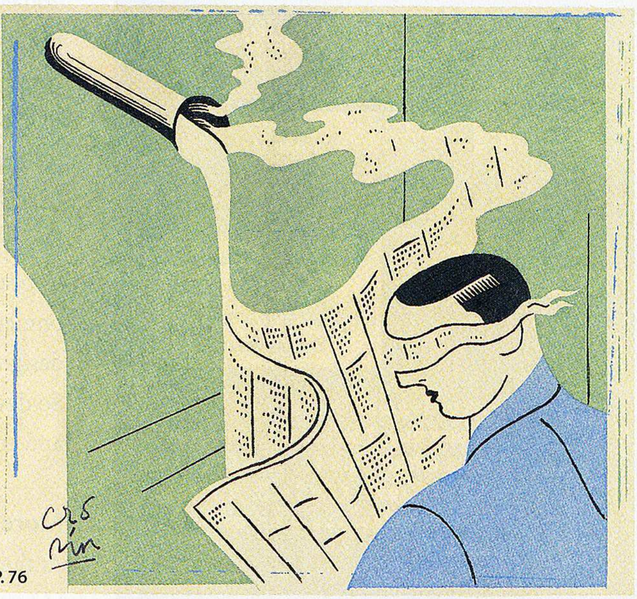
P.72

Departments

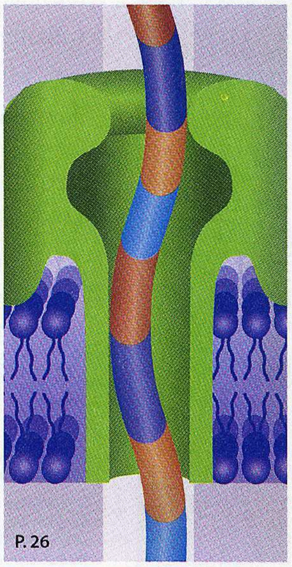


P. 28

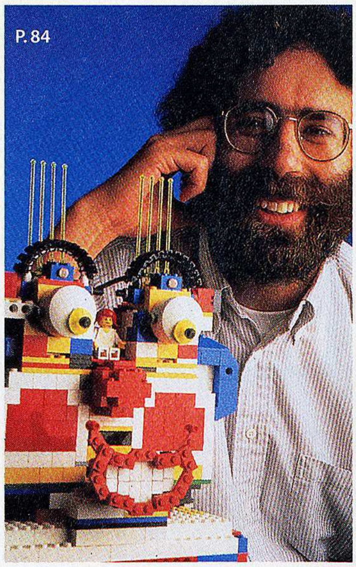
Columns



P. 76



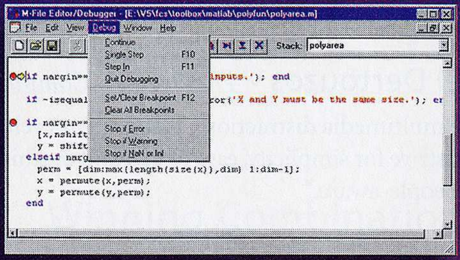
P. 26



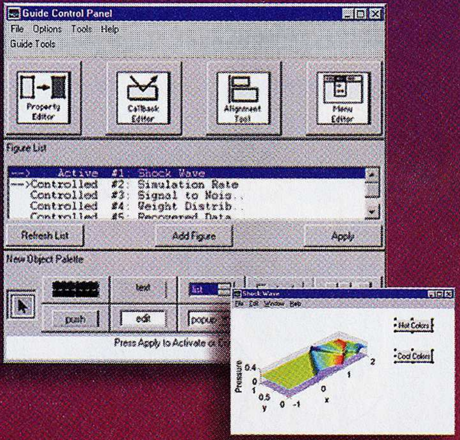
P. 84

Technology Review (ISSN 0040-1692), Reg. U.S. Patent Office, is published six times each year (January/February, March/April, May/June, July/August, September/October, and November/December) by the Association of Alumni and Alumnae of the Massachusetts Institute of Technology. Entire contents ©1998. The editors seek diverse views, and authors' opinions do not represent the official policies of their institutions or those of MIT. Printed by Lane Press, S. Burlington, VT. Second-class postage paid at Boston, MA, and additional mailing offices. Postmaster: send address changes to *Technology Review*, MIT, Building W59, 201 Vassar St., Cambridge, MA 02139, or e-mail to traddress@mit.edu. Printed in U.S.A.

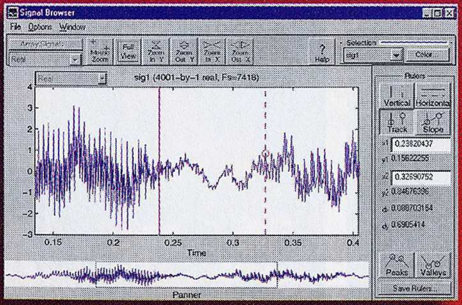
ABC audit applied for.



Application Development Tools
"We initially coded algorithms in MATLAB and then converted the MATLAB source to C or C++. To our surprise, the MATLAB code was faster in nearly all cases."
Jack Staub
Hughes Aircraft



Interactive GUI Design
"In one day, I wrote 875 lines of MATLAB which equates to 5,000 lines of C code. I had a functioning GUI in one day. You can't do that with C."
Kathleen Splaine
Risk International



Analysis and Visualization
"Anything from simple analysis to complex modeling and simulation can be done in a fraction of the time it would take to write your own code."
Gregory E. Chamitoff, Ph.D.
NASA, Johnson Space Center

We wrote exactly 698,794 lines of C code so that you don't have to.

More than 400,000 engineers and scientists use MATLAB to accelerate their technical programming. Here's why.

Faster programming

Today's most productive technical professionals have one thing in common – they use MATLAB instead of C or C++. Because, unlike a general purpose language, MATLAB is a complete, integrated analysis, visualization, modeling, and development environment specifically designed for technical computing. So development goes much faster and code is dramatically shorter.

More numerical power built in

At the heart of MATLAB is an easy to learn technical computing language with more than 500 functions built in. The MATLAB language includes flow control, multidimensional arrays, user-defined structures, ASCII and binary external data file access, and much more. And you'll save even more time with MATLAB Toolboxes, collections of highly optimized, discipline-specific functions written by world-class experts. You can even link in C, C++, and Fortran routines.

MATLAB 5 COMPILER NOW AVAILABLE

Less time coding means more time to think

Put simply, use MATLAB and it will take you far less time to develop finely tuned applications with revealing graphics, custom GUIs, and compact maintainable code. Now just imagine what you can do with the time you save.

See how MATLAB 5 can help you work faster. Visit our Web site for demos, examples, and updating information.

The MATH WORKS Inc.

MATLAB®
www.mathworks.com/mtrm
call 508-647-7000
e-mail info@mathworks.com

The MathWorks, Inc. 24 Prime Park Way, Natick, MA 01760 Fax 508-647-7001
Employment opportunities: http://www.mathworks.com/newjobs.html

The MathWorks is represented in the following countries: **Australia:** + 61-2-9922-6311 • **Benelux:** + 31(0)182-53-7644 • **Brazil:** + 55-11-816-3144 **Czech Republic:** 42-(0)2-68-44-174 • **France:** 33-141-14-67-14 • **Germany/Austria:** + 49-241-470750 • **India:** + 91-80-5-549338 **Israel:** + 972-3-561-5151 • **Italy:** + 39-11-240-80-00 • **Japan:** + 81-3-5978-5410 • **Korea:** + 82-2-556-1257 • **New Zealand:** + 64-7-839-9102 **Nordic Countries:** + 46-8-15-30-22 • **Poland:** + 48-126-17-33-48 • **Singapore/Malaysia:** + 65-842-4222 • **South Africa:** + 27-11-325-6238 **Spain/Portugal:** + 34(9)3-415-49-04 • **Switzerland:** + 41-31-954-2020 • **Taiwan:** 886-2-505-0525 • **United Kingdom/Ireland:** + 44-1223-423-200

INDEX

Changing Our Tense

FOR A WHILE NOW, WE'VE BEEN TALKING IN THE FUTURE TENSE ABOUT THE "NEW" *Technology Review.* The magazine *will be* about innovation, *will be* aimed at a broad audience, and *will* initiate a national dialogue on technology and innovation.

Now we can start talking in the present tense: Here it *is*. You are reading the first issue of a new incarnation of our 99-year-old magazine. This version is, as our cover proclaims, "MIT's Magazine of Innovation." That's a departure. As is everything else about this publication. We have new columnists, new departments, and (what you've surely already noticed) a new look, created for us by David Herbick, award-winning former art director of *Civilization.* Along with the design goes a new logo, fashioned for us by Don Morris, an acclaimed New York magazine designer who recently refurbished *Smithsonian.*

Knowing that everyone's time is short these days, we have sharply increased the magazine's allotment of brief, easily digestible items. The new "Prototype" department includes pithy reports from technology's front lines: specific technical advances. "Benchmarks" takes a wider view, with concise items on market trends, R&D strategies, basic research, and policy issues.

DAVID ZADIG

The substance of our new magazine lies in the features—six per issue, more than we've had before. Among the six are two close looks at technologies that are about to break out of the labs and into practical application: combinatorial materials and "prote-omics." Our story on Xerox PARC focuses on the process of innovation—how one famous research establishment is trying to link product development to fundamental inquiry into the nature of work. And our cover story takes an even broader view. In an excerpt from his new book, *The Productive Edge,* Richard Lester spells out the lessons winning companies offer our society.

In the "back of the book," you'll find several sections that focus on the intersection of technology and culture. "Viewpoint" offers provocative essays, such as this issue's sharply argued commentary on science journalism by Gary Taubes. "Pages" recommends some of the best new books on science, technology, and business. "Under the Dome" takes you behind the scenes here at MIT. "Trailing Edge" closes the magazine with nuggets from the history of technology.

We're also very proud of our columnists. In "The People's Computer," Michael Dertouzos, head of the MIT Laboratory for Computer Science, focuses on making computers easier to use and how, in the process, we can bridge the gap between technology and humanism. G. Pascal Zachary, who writes for *The Wall Street Journal* from San Francisco, is the voice behind "Inside Innovation," a column on what makes specific companies innovative. In his column ("Biology Inc."), Steve Hall, one of the nation's best science writers, covers the revolution in medicine brought forth by biotech.

As with any new publication, this is a work-in-progress. After all, innovation isn't just our theme—it's our animating spirit. Innovators learn, adapt, improve; so will the new *TR.* In fact, we've already taken our first giant step by changing our tense and walking into the present. We're here. Hello.

—John Benditt

MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

EDITOR IN CHIEF
John Benditt

SENIOR EDITORS
Herb Brody
David Rotman
Mary Tamer

ASSOCIATE EDITORS
Antonio Regalado
Abigail Mieko Vargus
Rebecca Zacks

CONTRIBUTING WRITER
Robert Buderi

EDITORIAL ASSISTANT
Deborah Kreuze

PRODUCTION MANAGER
Valerie V. Kiviat

COPY EDITOR
Troy Martin

DESIGN CONSULTANT
David Herbick

TECHNOLOGY REVIEW BOARD
Christian J. Matthew (Chair)
John Benditt
Woodie C. Flowers
Bernard A. Goldhirsh
Barbara Goldoftas
William J. Hecht
R. Bruce Journey
Alan P. Lightman
Victor K. McElheny
Robert M. Metcalfe
DuWayne J. Peterson, Jr.
Philip R. Sayre
Edward T. Thompson
G. Mead Wyman

SUBSCRIPTIONS: 800-877-5230, fax 815-734-5237, trsubscriptions@mit.edu; cost $30 per year, Canada residents add $6, other foreign countries add $12.

QUESTIONS: 617-253-8292, trsubscriptions@mit.edu

ADDRESS CHANGES: General 815-724-1207, traddress@mit.edu; MIT Records 617-253-8270

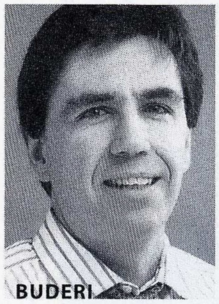
PERMISSIONS: 617-253-8292, trcomments@mit.edu

REPRINTS: 717-560-2001, sales@rmsreprints.com or http://www.rmsreprints.com

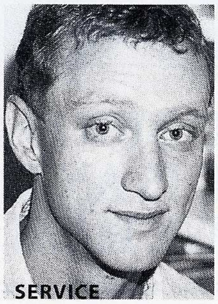
TECHNOLOGY REVIEW
201 Vassar St., W59-200
Cambridge, MA 02139
Tel: 617-253-8250
Fax: 617-258-8778
trcomments@mit.edu
http://web.mit.edu/techreview

VOICES *Contributors to Our Pages*

The cover story in the first issue of the "new" TR—"Companies That Listen to Their Inner Voices"—is written by one of MIT's own: **Richard Lester**, director of the Industrial Performance Center. Richard is a soft-spoken Englishman who was trained as a nuclear engineer. For more than a decade, however, his main interest has been the productivity—or lack thereof—of the U.S. economy. The article is excerpted from his new book, *The Productive Edge,* to be published in May by W.W. Norton.

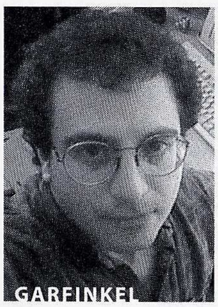

BUDERI

Xerox's Palo Alto Research Center is a famous place. Famous for inventing the personal computer, the graphical user interface, the Ethernet, the mouse, the color printer—and then failing to exploit them for the parent company. That's an old story. We wanted a fresh one about this storied institution. So we turned to Cambridge-based writer **Bob Buderi**, whose book (*Radar, The Invention That Won the War*) is rapidly becoming a classic in the popular literature on technology. His story for us ("Fieldwork in the Tribal Office") fits nicely into his latest project: a book on corporate R&D strategies.


SERVICE

For our story on the exotic and very hot new field called combinatorial materials, we found a relatively young writer who's making a mark for himself in science and technology journalism: **Bob Service**. Bob is on the staff of *Science* in Washington, D.C.

For his piece on Boston's Big Dig, **Simson Garfinkel** tramped through the construction site and listened to a lot of engineers talking about the details of their craft. Fortunately, he's well placed to understand them: He's an MIT graduate himself. For Simson, this foray into the world of the big earth movers is somewhat unusual. He's a prolific writer (a regular for *Wired* and a columnist for *The Boston Globe*), but his main beat is information technology.


GARFINKEL

Two of our features were written by members of the *TR* staff—one new and one old. The seasoned hand is **Herb Brody**, who's been a Senior Editor at *Technology Review* for eight years. Before coming to *TR,* Herb had acquired a track record as a top technology journalist at *High Technology* and *PC/Computing.* He conducted his penetrating interview with Vint Cerf over the Internet, Cerf's creation. The interview reflects Herb's deep interest in information technology, an interest that's also on display in his "Web Crawl" column.

The new member of our team is **Antonio Regalado**. Antonio arrived on Vassar Street in January and was immediately put to work reporting on the brand-new field of "proteomics." Antonio, a New Yorker, joins us from Windhover Information Inc., a publisher of insider newsletters about biotechnology.


TAUBES

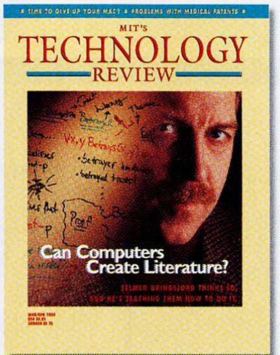
Finally, the first of our "Viewpoints" is written by **Gary Taubes**—and a provocative piece it will no doubt be for his fellow science journalists. But then, Gary thrives on controversy. His great labor of love was a book called *Bad Science*—an excellent account of the fiasco known as cold fusion. Gary, a frequent contributor to *Science, The Atlantic Monthly,* and *The New York Times Sunday Magazine*, recently moved from Boston to Los Angeles to escape gloomy winter weather. It will take more than a move to the Left Coast to change his worldview, however.

"Bringsjord's claim that computers can't be conscious is like someone saying in 1900 that television is impossible."

Chess Is Too Easy

IN HIS ARTICLE "CHESS IS TOO EASY" (*TR March/April 1998*), Selmer Bringsjord writes that machines will never know what it's like to experience Paris in summer, and so on, like people do. This, to me at least, sounds as if machines simply need better sensory systems, along with a better way to extract information from those systems.

I would suggest a tentative belief in Strong AI on the grounds of parsimony. Weak AI states that there are at least two different things in the universe: the human mind and everything else. Since we have no persuasive evidence that the human mind is indeed qualitatively different than everything else, we should not assume that it is.



JAMES POLICHAK
Stony Brook, NY

SELMER BRINGSJORD'S PROPOSAL THAT THE ability to write a story is a better measure of machine intelligence than the ability to play chess is cogent and intriguing, but his work on Brutus.1, like the creation of Deep Blue, focuses on the "how" of human endeavor instead of the "why." I will be willing to believe in a machine consciousness not when one *can* write a story, but when one, driven by a need to express itself, *must* write a story.

FRANK VENUTI
Big Flats, NY

IT'S VERY DIFFICULT TO ARGUE THAT A SCIentific breakthrough is impossible. The best such arguments typically show that the breakthrough contradicts a proven physical principle. For example, I believe that the Shannon coding theorem "proves" that 56-kilobit-per-second modems can't exist.

Bringsjord claims that to write a credible story, a computer has to best John Updike. Does that mean I'm an idiot because I haven't won a Nobel Prize? In fact, the computer-generated story accompanying the article is better than anything I've ever written.

Bringsjord also writes, "I expect to be able to say with some authority that machines can't be creative and conscious (seeing as how I'm using state-of-the-art techniques)." This is analogous to someone stating in 1900 that television is impossible because they hadn't been able to build a TV set using "state-of-the-art techniques." Mercy!

DAVID ESPINOSA
Palo Alto, CA

BRINGSJORD ASSERTS THAT "humans find it impossible to produce literature without adopting the points of view of characters." Adopting the characters' viewpoints is a useful tool, but only one among many. It is completely possible to write stories without using that device. One might argue that writing "literature"—as opposed to mere "stories"—requires this particular tool. But that places one in the strange position of arguing that Garcia Lorca is more human than I because he writes literature while I merely write stories.

Bringsjord writes that computer-generated novels exist in "a future [which] simply can't be conceived." I would counter that this is a failure of his imagination, not the product of any rigorous argumentation.

ALAN WEXELBLAT
Cambridge, MA

BRINGSJORD CARELESSLY STATES IN HIS otherwise good article: "And what if it [Deep Blue] could combine this processing horsepower with a pinch of knowledge of some basic principles of chess—for example, those involving king safety, which, incidentally, were installed in Deep Blue just before its match with Kasparov?"

This "pinch of knowledge" was an exhaustive process of refinement over the course of at least two years, including top-notch consulting by grandmaster Joel Benjamin (currently U.S. champion) and more than 10,000 evaluation weights covering king safety, among many other considerations. These were not thrown in at the last minute like an irrelevant afterthought.

Deeper Blue's evaluation weights placed imperfect value on its knights under certain circumstances. Kasparov exploited that to win the first round. IBM and Benjamin adjusted the weights overnight, and Deeper Blue came back fighting in a distinctly different manner the next round. Deeper Blue didn't learn anything from its loss; it was manually adjusted by its human conspirators who themselves had actually learned from the loss and formulated solutions.

If Deeper Blue had adjusted itself during the Kasparov match, with no human assistance whatsoever, then we chess players might be concerned. Until such time, we have no basis to make claims about computers being better than humans at chess. A one-time match against a single grandmaster does not mean chess is too easy.

DAVID BRINEGAR
Berkeley, CA

Bringsjord responds:
Polichak suggests that computers could experience a Paris spring if they had "better sensory systems." But AI has been there, done that: The world's best robots, such as those exhibited at major AI conferences, have sophisticated sensors and effectors—yet they don't experience anything like the raw feel of climbing the Eiffel Tower in a crisp sunlit breeze. Computing machines just move symbols around, which will never produce raw feels.

As to Polichak's preference for Strong AI over Weak AI on grounds of parsimony: Mathematically speaking, the universe is divided into *three* classes from the standpoint of computers: things that cannot even solve problems solvable by running algorithms, things that can solve problems by running algorithms, and things that can also solve problems too difficult for algorithms to solve. Computers fall exclusive-

We welcome letters to the editor.
Write: *Technology Review*, MIT Building W59, Cambridge, MA 02139. Fax: (617)258-8778. E-mail: technology-review-letters@mit.edu. Please include your address, telephone number, and e-mail address.
Letters may be edited for clarity and length.

ly into the second class. For all we know now, minds could fall into the third. If so, Strong AI is stone cold wrong.

Espinosa tells us that it's "very difficult to argue that a scientific breakthrough is impossible." Not so. To argue that computers will never do X, all one needs to do is show that doing X requires processing uncomputable functions, of which there are many.

Wexelblat points out that it is possible to write stories without adopting the characters' points of view. True enough. But I affirm Wexelblat's distinction between stories and literature. To write the latter, one does need to adopt the points of view of characters. And the issue is not who is more human, but who is a better writer. Likewise, in the case of chess, the issue is not whether Deep Blue or Kasparov is more human. (Gary wins this one hands down: *he* got tired.) The issue is who is the better chess player.

Brinegar points out that many of the principles underlying Deep Blue's prowess were "not thrown in at the last minute like an irrelevant afterthought." I never said something was thrown in as an *afterthought*; no doubt there were good reasons for all the late modifications. But that some principles *were* incorporated into the machine's software at the last minute has been revealed by members of the Deep Blue team.

Brinegar says that if Deep Blue had been able to adjust itself during the Kasparov match, then human chess players might be concerned. But there is an algorithm, easily proved, for playing invincible chess *without learning*. With constant increases in computing power, future machines will defeat Kasparov's brightest descendants in match after match, invariably and unfailingly. To find a problem worthy of mind-machine competition we need to choose from those that aren't known to be computationally solvable. Creating literature belongs firmly in that category.

To Mac or Not to Mac?

DAVID SHENK HAS GIVEN WINDOWS advocates an undeserved playing chip by rating their platform a near-substitute for the Mac ("To Mac or Not to Mac," *TR March/April 1998*). It just ain't so. Sure, a mouse is a mouse and an icon is an icon, but once you get past the point-and-click similarity, Windows' instability turns a day's work into a cybernetic horror show. The IS people in my PC-equipped office

are kept running with relentless crashes, lost e-mail, and locked-up print jobs.

WILLIAM J. HICKEY
Clinton Township, MI

LIKE SHENK, I PREFER THE MAC AESTHETIC. And in seven years, I don't think I've spent more than two hours total on the phone to tech support. I've seen my Windows 95 brother-in-law spend more time on the phone just to get "Where in the World is Carmen Sandiego?" running.

TOM BARTA
Evanston, IL

THE OTHER MORNING, I WAS LISTENING to a local radio computer call-in show. Several listeners had called about problems with Windows 95. The three hosts spent 15-20 minutes trying to help one caller. The frustrations heard in the caller's and hosts' voices as they tried, without success, to solve the problem only made me happy that I was using the interface that Windows 95 was attempting to emulate.

BERNIE SHAPIRO
Lowell, MA

SHENK DID NOT DISTINGUISH ENOUGH between Apple Computer Inc. and the Macintosh operating system. Apple failed in its charter to spread Macs over the globe because it insisted on selling both hardware and software. Microsoft sells only software, which can be put into anyone's computer. If Apple were to do that, the MacOS could prosper. In fact, perhaps the best thing that could happen for Macintosh users would be for Apple to go out of business and for the MacOS to become public domain.

ROBERT BOURQUE
Naka, Japan

A COUPLE OF THINGS ARE MISLEADING IN Shenk's story. First, although Beta video recording failed as a consumer technology, it is now the *de facto* standard for professional video. Second, it's true that Windows commands around 70 percent of what Dataquest and other market-research firms call "marketshare." But this figure represents a portion of quarterly sales. The true market share of the Macintosh, if measured by installed base, would be 30 to 40 percent.

TOM IERNA
St. Petersburg, FL

FOR ANYONE WHO HAS CONSIDERED THE Windows 95 "Start" button and program bar enough of a reason to ponder leaving the Mac: The same features are available for the Mac in the form of a shareware control panel called "GoMac" from Proteron.

PAUL FREDERICK
Via the Internet

THE WINDOWS VS. MACINTOSH DISCUSSION need not be an either-or proposition. Any reasonable Power Macintosh can run Virtual PC—software that emulates Windows 95. In fact, I contend that the best way to run Windows 95 is not on an Intel box but on a Macintosh G3. Operating on a software machine instead of in hardware, Windows 95 boots and shuts down faster.

WAYNE YARNALL
Via the Internet

Cashing in on Medical Knowledge

THE SCARE INTRODUCTION TO "CASHING IN on Medical Knowledge" by Seth Shulman (*TR March/April 1998*) gives the wrong impression of the value of patents to the introduction of new medical procedures. If

patent protection were not available, there would be a vast reduction in medical research, which is expensive and getting more so. Few companies, or individuals for that matter, would be willing to do the necessary work if anyone could simply copy their successful work and not have the expense of failures. Moreover, patents do not endanger the public: whenever public health is a concern, the U.S. government has the power to commandeer the use of any patented medicine, device, or procedure.

ALVIN GUTTAG
Patent Attorney
Gaithersburg, MD

Brain Drain

I WAS PERPLEXED BY THE ARTICLE "OTHER Countries' Money" by Richard Florida (*TR March/April 1998*). I think, under the guise of "research and development," a rather blatant buying-out of brain power is being conducted in the United States, where innovation has always been strong. Once Asian companies reduce this strength in American products, they will be more competitive (again) globally. In the long run, today's financial benefits will cause tomorrow's financial agony, but corporate directors have always had difficulty seeing beyond today's bottom line and personal bonuses.

RONALD K. SIBLEY
Hilton Head, SC

Explosives Sniffing

READING "A SNIFF IN TIME" (*TR MARCH/April 1998*) I was astounded to find no mention of how those developing this device intend to deal with people who legitimately handle explosives and propellants. I am a target shooter and reloader, and do not want to miss my flight due to being hauled off by security guards and interrogated. And what about the farmer—or even the person who just repotted a plant with fertilized soil? Nitrates and other explosive-related compounds are so common in both nature and industry that false positives might outweigh legitimate positives by several orders of magnitude.

RODFORD E. SMITH
Frankfort, KY

Engineer Chuck Rhykerd responds:
Smith expresses a common concern. There are many legitimate activities that would bring passengers in contact with explosives. Passengers who trip the alarm could be questioned or asked to walk through the portal a second time—just as airports now handle metal-detector alarms. Because the detector identifies the type of explosive, questioning can be very effective. For example, if we detect an explosive used in heart medication, and the passenger has a vial of those pills in his shirt pocket, the alarm can be quickly dismissed. In most cases resolving an alarm should take less than a minute, if the passenger is cooperative.

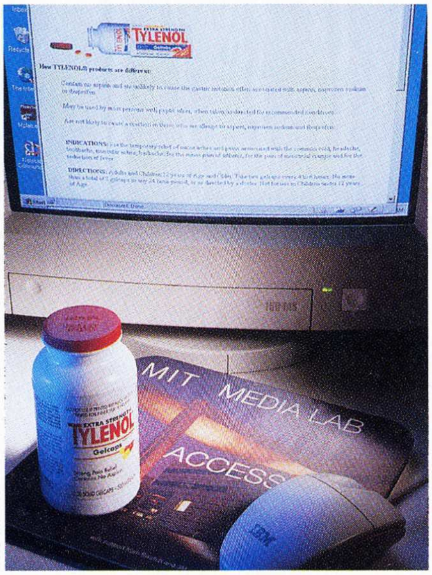
Clearly the security benefit must balance the passengers' perceived risks and inconvenience. Frequent flyers know that they can avoid delay at the metal detectors that are in airports today by taking their keys out of their pockets and leaving their steel-toed shoes at home. A similar list of helpful actions by passengers will evolve for explosives screening at airports. But the security benefit must balance the passengers' perceived risks and inconvenience.

CHUCK RHYKERD
Chemical Engineer
Sandia National Laboratories
Albuquerque, NM

Pad Power

While computers have gotten faster and software fancier, the humble mousepad has remained happily low-tech. But researchers at the MIT Media Laboratory are now converting the unassuming slabs of foam into information-input devices. The Media Lab's "smart mousepad" (which draws power from the keyboard connector) reads information from a simple electronic tag that can be implanted in a variety of objects.

After the mousepad reads the tag, software connects to an online database to find out what to do. Consumer goods might pull up manufacturers' Web sites. Setting a tagged bottle of medicine on the pad, for example, could call up the drug company's Web page, offering more information about the medication than is included with the packaging. The Media Lab's Henry Holtzman imagines his 3-year-old using tagged tokens to call up online images of her favorite things.



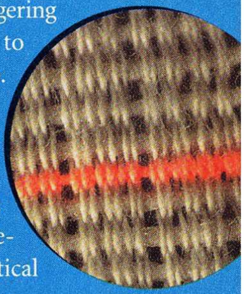
WEBB CHAPPELL

STANLEY LEARY

They're not just for texture anymore

Where Does It Hurt?

A vest designed at Georgia Tech for the U.S. Navy could instantly tell medical personnel where a wound is. Woven through the vest is an optical fiber. Precisely timed light pulses are launched into the fiber and strike a photodetector at the other end. A bullet would break the fiber, interrupting the light signal and triggering a transmitter to summon help. Light is reflected by the broken fiber to the source; timing the return of the optical echo permits the system to compute the location of the break and thus of the injury. Sensors woven into the garment can continuously monitor vital signs and feed the information to a portable computer worn on the hip—a kind of high-tech dog tag. A fallen soldier's position and physical status can be automatically transmitted to a triage unit. Such a garment could appeal to a broader class of potential users, including athletes in training.



When the glow stops, there's trouble

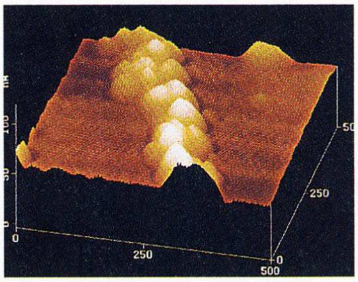
Coming Soon to the Internet Near You

Butter up some popcorn and plop yourself down in front of your computer. Feature-length Internet movies are on the way, if a collaboration in England between a movie production company and a software firm bears fruit.

The scheme hatched by Maveric Media Productions and Cathedral Software requires filmmakers to use digital cameras and make do with 12 frames per second rather than the conventional 24. This change will encourage frequent scene changes to mask the slight jumpiness that the lower rate produces. To smooth out the flow of bits, the system will send information about action scenes during the lull of the still ones. Maveric and Cathedral hope to distribute the first film prepared for Net distribution—"The Judas Kiss"—by the end of next year.

Nanotech: Design by DNA

One goal of nanotechnology is to create electronic devices on the nanometer (billionths of a meter) scale. But making such tiny devices has been held up because moving nanoscale building blocks around one by one to form wires and components is so difficult. Now scientists at the Technion-Israel Institute of Technology in Haifa say they have formed silver nanowires using DNA as a template. The researchers stretched strands of DNA between two gold anchors, using disulfide groups on the DNA as the glue. They exposed this scaffolding to a solution of silver ions, which are attracted by the negatively charged DNA. A standard chemical agent reduces the ions to silver metal, producing 100-nanometer-wide silver wires.



AMERICAN TECHNION SOCIETY

Silver atoms, single file

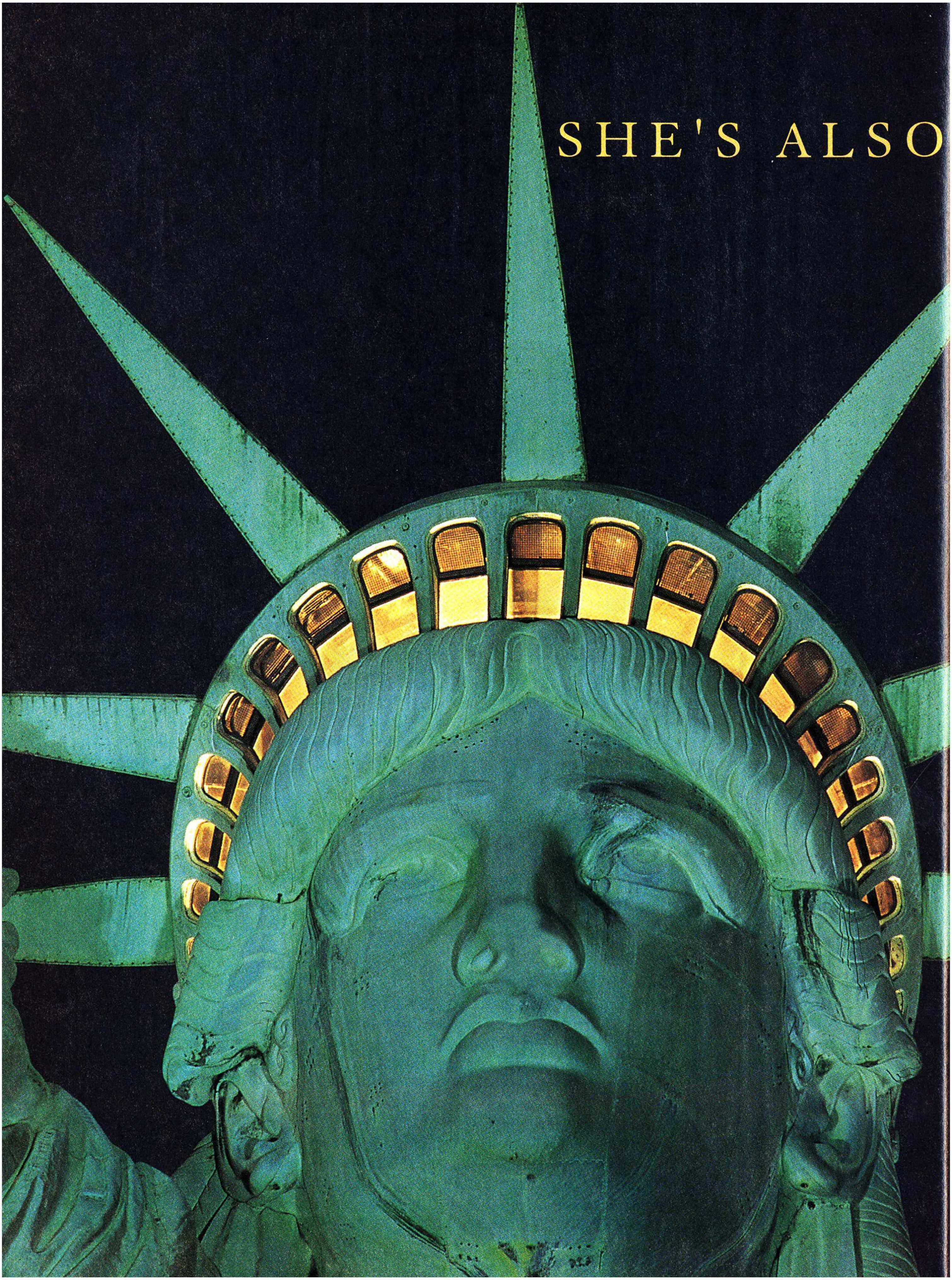
An Electrifying Sight

A Wheaton, Ill., startup founded by an ophthalmologist is working on an artificial silicon retina that could restore sight to those suffering from macular degeneration—the leading cause of blindness in people older than 65. The device is a silicon wafer 3 millimeters across covered with photodiodes. With the wafer implanted in the retina, the photodiodes convert light into electrical impulses that travel through the optic nerve to the brain. The photodiodes will be packed so densely that the "resolution will theoretically be as good as normal vision," says Optobionics founder Alan Chow; Stanford University's Nanofabrication Center is collaborating on the miniaturization.

The implant has induced retinal activity in animals, but studies with human volunteers are more than a year away. Because the photodiodes are sensitive to infrared as well as visible light, Chow says these first subjects may report some odd sightings, such as beams shooting from a TV remote control.

OPTOBIONICS CORP.

Silicon implant restores vision


SHE'S ALSO

Let My Computer Serve Me!

I'M JUST BACK FROM THE WORLD ECONOMIC Forum in Davos, Switzerland, where besides Hillary and a few hundred ministers and prime ministers, there were also some 1,500 CEOs representing $4 trillion of gross revenue—among them the leaders of nearly every computer, software, and communications company, including Michael Dell, Bill Gates, and Larry Ellison. In a session I chaired among these executives, we sought to determine the top issues ahead for the developers of information technology. At the top of the list: *Ease of use.*

Ease of use—a term I much prefer to "user friendly"—is one of several important issues at the junction of our technology and our humanity that we will explore in this new column.

A machine would be simplest to use if it were intelligent. Never mind if it is swelling with multimedia and colorful three-dimensional animals floating in space. Just give me a keyboard with an impact printer that understands me as well as my human assistant does, and I'll throw away all the fancy hardware and software. Well, that's impossible today and it will be in the near future, at least for the kind of general intelligence we call common sense. We don't know how to do it in practice or in the lab (which precedes practice by a decade).

We can, however, make our systems more intelligent by specializing them into particular, narrow contexts. In fact, it's scandalous that we haven't done so yet. In the industrial era we gave different tools to different workers—doctors, mechanics, plumbers, gardeners—but in the information age we are trudging along with the same word processor, spreadsheet program, database, and graphics editor for musicians, accountants, engineers, and lawyers! This mindless generality must give way to greater specialization among the different human interests and professions. With the right tool, it will be easier to get the job done.

Following specialization, we need to create interfaces tailored to humans. People are not born with keyboard sockets or mice attached to their bodies. Instead, we use our mouths and ears. Why not engage our machines with the same natural human interfaces? Speech-understanding technology has come a long way since researchers began prematurely touting its capabilities. A few useful systems are already commercially available.

More sophisticated ones offering information in specialized areas such as weather, navigating a city, or booking airline tickets have been implemented in the MIT Lab for Computer Science by Dr. Victor Zue and his research team. They comprehend some 90 percent of the queries uttered by normal people. When they make a mistake, the user catches it and restates the query, just as we do with people who don't understand us the first time. Systems like these should be within commercial reach in five to seven years and should noticeably improve ease of use.

Adapting computer systems to human capabilities should be extended beyond specialization and speech to a greater awareness of what is important to people, rather than to machines: A new breed of people-aware systems would stand ready to handle our wishes, expressed in ways that are natural, even unconscious, for us. They would focus on human habits and mindsets as their predominant driving force and they would strive to shrink today's considerable gap between human and product orientations. With such an attitude, designers would work hard at watching what users do and how they do it, through many successive prototypes…before releasing their products.

A new breed of "people-aware" machines should stand ready to handle our wishes, expressed in ways that are natural, even unconscious, for us.

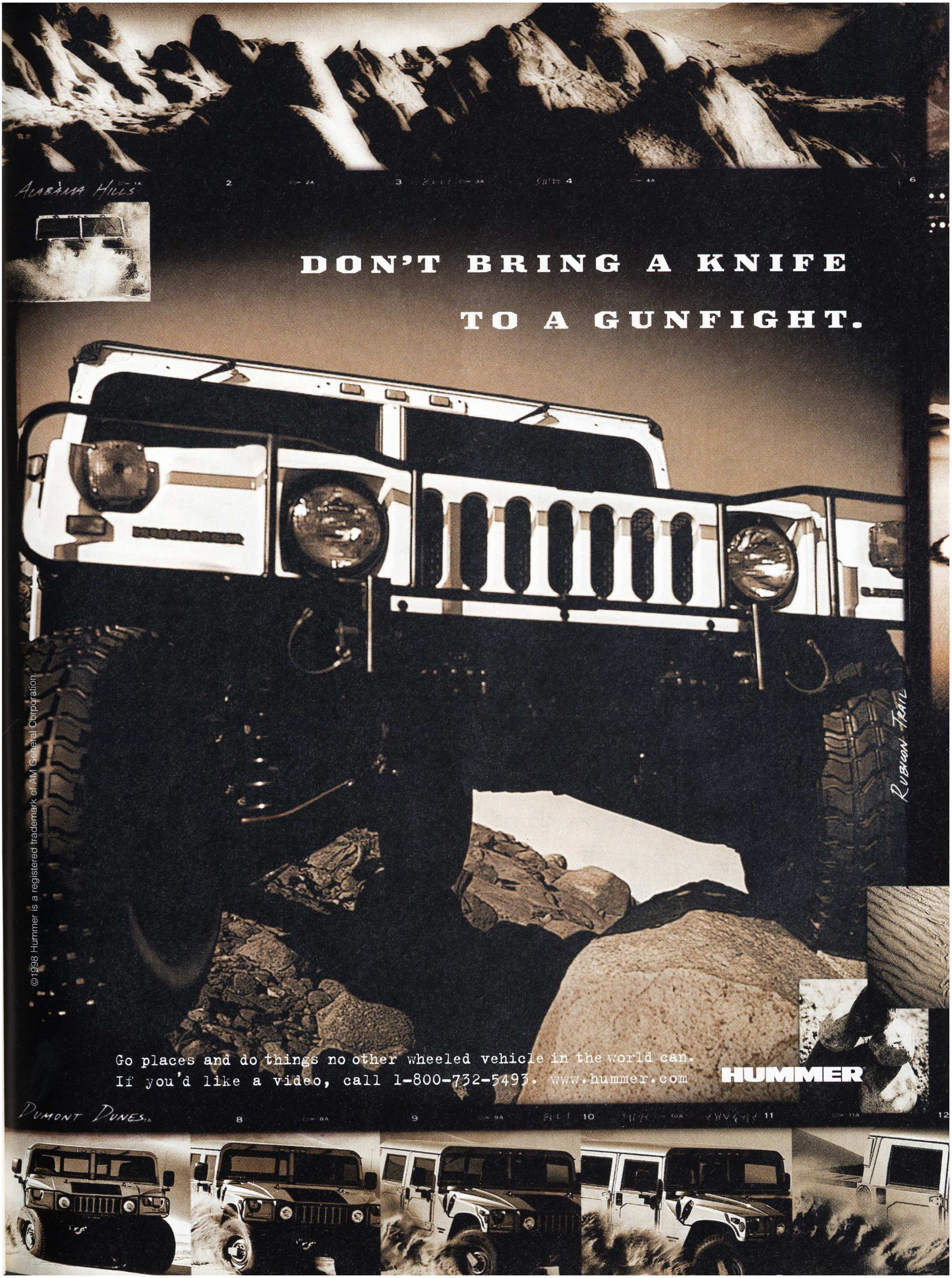
DAVID ZADIG

Simplicity is another key to ease of use. I often hear the mantra that computers manage complex systems and are therefore inherently complex. Baloney! Humans have always simplified the world to understand it. We can begin by throwing away 90 percent of the features that come in today's bloated software—most of which are intended to impress us and motivate us to buy. Software suppliers should strive to produce (and users should favor with their purchases) software that comes with the minimum number of features needed to get the job done.

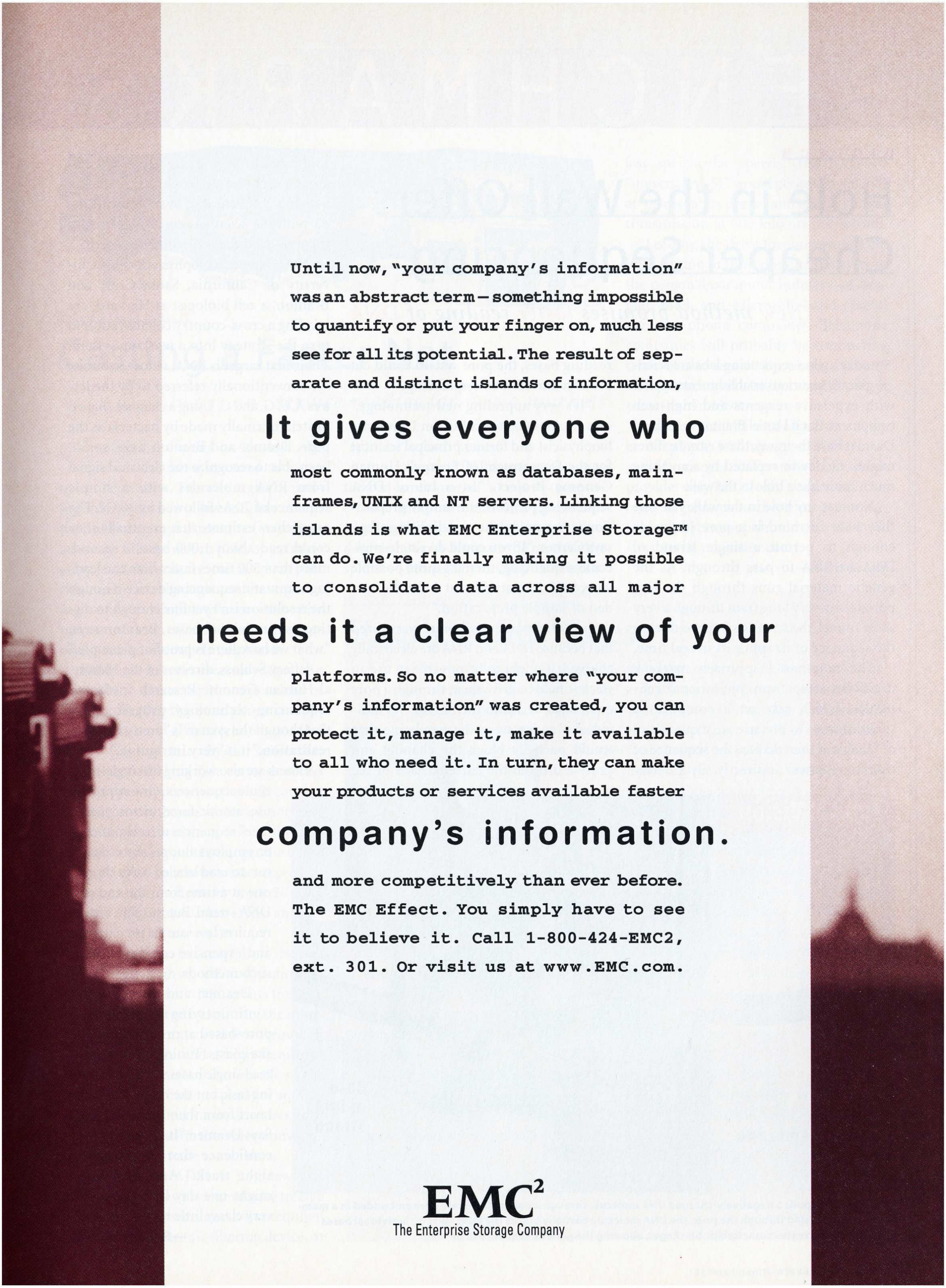
There's still more that can be done: We should not have to wait as long as we do today to get a response from our systems. And our computers should not crash as easily as they do. We have constructed telephone systems that seldom, if ever, crash, yet are made up of more complex software than our personal computer systems.

Both problems will recede as communications become faster and systems become more reliable in the next decade and beyond. We can also invent useful "languages" that blur the distinctions between programmers and users, as do spreadsheets and the Web's HTML, so that people may easily customize systems to needs.

Doing these things is a tall order. But ease of use is not impossible—just difficult. So, designers and users alike: Let's go after the top issue of the year. We can make a difference, starting now.


ALABAMA HILLS
DON'T BRING A KNIFE
TO A GUNFIGHT.
RUBICON TRAIL
Go places and do things no other wheeled vehicle in the world can.
If you'd like a video, call 1-800-732-5493. www.hummer.com
HUMMER
DUMONT DUNES
©1998 Hummer is a registered trademark of AM General Corporation.


THE
EMC
EFFECT™


Until now, "your company's information" was an abstract term—something impossible to quantify or put your finger on, much less see for all its potential. The result of separate and distinct islands of information,
It gives everyone who
most commonly known as databases, mainframes, UNIX and NT servers. Linking those islands is what EMC Enterprise Storage™ can do. We're finally making it possible to consolidate data across all major
needs it a clear view of your
platforms. So no matter where "your company's information" was created, you can protect it, manage it, make it available to all who need it. In turn, they can make your products or services available faster
company's information.
and more competitively than ever before. The EMC Effect. You simply have to see it to believe it. Call 1-800-424-EMC2, ext. 301. Or visit us at www.EMC.com.
EMC²
The Enterprise Storage Company

BENCHMARKS

BIOTECH

Hole in the Wall Offers Cheaper Sequencing

New method promises faster reading of DNA

Today's gene-sequencing labs are scientifically luxurious establishments, replete with expensive reagents and high-tech equipment. But if Daniel Branton and David Deamer have their way, these ritzy facilities might one day be replaced by something much more like a hole in the wall.

Not just any hole in the wall: The one they have in mind is a pore just wide enough to permit a single strand of DNA or RNA to pass through. As the genetic material runs through the tiny portal like a very long train through a very short tunnel, the scientists hope to discern the sequence of its subunits in real time.

The pore-based approach marks a drastic departure from conventional techniques, which rely on a complicated series of steps to prepare large quantities of DNA and then deduce the sequence of subunits (bases) indirectly. By directly reading bases, the pore system could cut the cost and time of sequencing.

"It's very appealing new technology," says Charles Cantor, a Boston University biophysicist and former principal scientist for the Department of Energy's Human Genome Project. "In a lot of DNA sequencing projects, the sample preparation is becoming the cost-limiting step," says Cantor. "If you could do single-molecule sequencing, then it's quite possible you could dramatically cut down the burden of sample preparation."

In 1991 Deamer and Branton realized that because DNA and RNA are electrically charged, it ought to be possible to use an electric field to drive them through a pore embedded in a thin membrane. As individual strands traverse the membrane, they would partially block the channel and cause a drop in the current. Each of the four bases in DNA or RNA is a different size, so each should block the channel in a slightly different way; by monitoring the current, the scientists could—at least in theory—read the molecule's sequence.

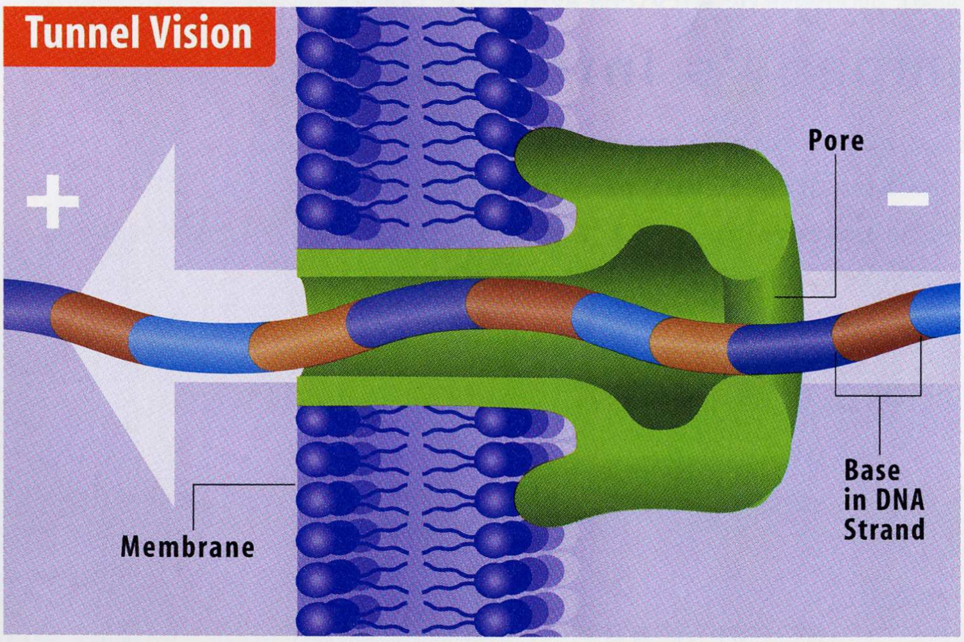
Now Deamer, a biophysicist at the University of California, Santa Cruz, and Branton, a cell biologist at Harvard, are heading a cross-country collaboration to turn the strategy into a working system. Their first target is RNA, whose subunits are conventionally referred to by the letters A,U, G, and C. Using a channel-shaped protein normally made by bacteria as the pore, Deamer and Branton have, so far, been able to recognize the electrical signal from RNA molecules with a simple sequence of 70 As followed by 30 Cs. The researchers estimate that eventually they could read about 1,000 bases a second, more than 500 times faster than the leading automatic sequencing device. Though the resolution isn't yet fine enough to distinguish individual bases, Branton says, "what we have here is proof of principle."

Jeffery Schloss, director of the National Human Genome Research Institute's sequencing technology program, says that though the system is "pretty far from realization," it is "very intriguing."

Others are also working on single-molecule sequencers. One approach uses atomic-force microscopes to "see" sequences directly; another employs fluorescence detectors to read labeled bases clipped one at a time from the end of a DNA strand. But the pore system requires less sample preparation and expensive equipment than such methods.

Deamer and Branton will continue trying to optimize the pore-based approach on opposite coasts. Tuning the system to read single bases will be a daunting task, but the researchers take heart from their recent success. Says Deamer: "It gives us a lot of confidence that we're on the right track." And that track might one day lead them to a very classy little hole in the wall.

—Rebecca Zacks

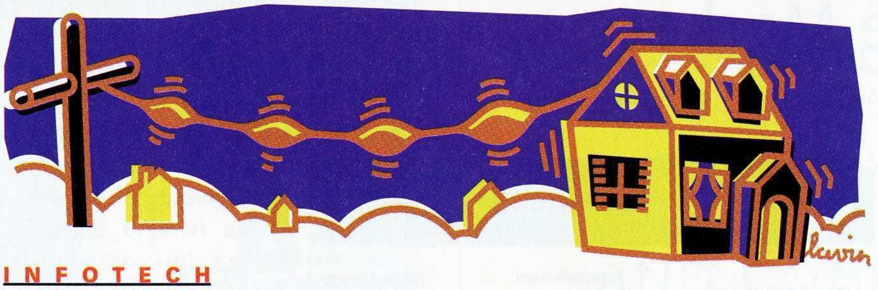


DAVID FOSTER

An electric field pulls a negatively-charged DNA molecule through a nanometer-scale pore embedded in a membrane. While passing through the pore, the DNA molecule partially blocks the ionic current; individual bases (DNA subunits) create characteristic blockages, allowing the genetic sequence to be read.

Reports from the world of innovation: Market Developments, R&D Trends, Technology Policy, Basic Research

IN THIS ISSUE: NANOTECH, INFOTECH, BIOTECH, DRUG DEVELOPMENT, CANCER THERAPY, POLICY, MATERIALS RESEARCH, INVESTMENT



DANIEL PELAVIN

INFOTECH

Casting a Faster Net

"Always on" service readies for home markets

Sometimes it seems as though the Internet had been invented to foster manic depression. There's the glee of finding information in a few seconds. Then, the head-banging frustration of waiting as an image fills the screen pixel by excruciating pixel. Most home Net users, in particular, sip data through modems operating at 28.8 kilobits per second. The newest modems offer 56 kilobits per second—not an overwhelming boost.

But home Internet users may soon have available to them the Net equivalent of lithium. Starting this year, phone companies will begin to offer a technology called ADSL (asymmetric digital subscriber line) that will bring fast network access through the copper wires that still connect virtually every home to the phone network. Anyone within a few miles of a phone switching center can get the benefits of ADSL—connection rates exceeding today's fastest modems by some 20-fold. And an ADSL connection is like an electrical socket: It's always on.

ADSL works because most households need high-speed connection in only one direction. ADSL grants the high downloading speed by splitting the information stream in two—a low-frequency channel for voice and a high-frequency one for data. This separation allows the copper to carry data at speeds of up to 7 megabits per second in one direction without interfering with the voice conversations that occupy the same wires.

The idea for ADSL is not new. But phone companies have until now treated it as an exotic service, and it has required installing an electronic filtering device, or "splitter," at each home.

To accelerate ADSL's penetration into the consumer market, a host of computer and telecommunications companies have joined forces to push for a new standard that would eliminate the need for the splitter—although by limiting data rates to less spectacular speeds. The so-called "universal ADSL" would permit downloads at 1.5 megabits per second and upstream transmission at 500 kilobits per second.

Leading the drive for universal ADSL is a coalition of three dominant players in the personal computer industry—Compaq, Intel, and Microsoft—and several regional phone companies. Telephone companies will probably be conducting trials of the service by year's end, and widespread availability should begin sometime in 1999.

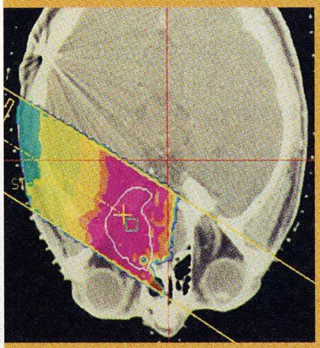
ADSL should have an edge over another telephone technology—ISDN (integrated services data network), which provides only 128 kilobits per second. This latest ingredient in the telecommunications alphabet soup should provide more substantial nourishment.

—Herb Brody

CANCER THERAPY

Steady as She Goes

When Steven Dubowsky saw the details of Massachusetts General Hospital's (MGH) planned proton beam therapy center several years ago, he immediately realized that its high-tech robotic apparatus for positioning patients was not nearly precise enough.



MASS. GENERAL HOSPITAL

Proton beams target cancer cells.

Dubowsky, a robotics expert at MIT and an advisor to the MGH facility, spent the next two and half years solving the problem. By writing an elaborate algorithm that compensates for imprecision inherent in the equipment and designing an array of sensors to detect the different sizes and shapes of patients, Dubowsky and coworkers at MIT improved the system's accuracy by an order of magnitude. When the MGH facility, which will treat patients with inoperable brain tumors, opens within the next year, it will use software for the patient positioning apparatus based on Dubowsky's work.

Proton treatment is favored over conventional X-ray radiation in treating some tumors precisely because it can target cells far more accurately. "The goal [of the facility] is to point a beam of radiation at the tumor and avoid treating nearby material," says Michael Goitein, MGH's project director. At least three other dedicated proton centers are being built in the United States. "I'm sure they'll use this or similar software," says Goitein.

While the facility's initial plans called for targeting the proton beam with an accuracy within a half-millimeter, Dubowsky says early tests confirmed his hunch: The system, which is being built by Ion Beam Applications, a Belgium-based company, was actually achieving accuracy no better than 5 millimeters.

Dubowsky holds his forefinger and thumb slightly apart. "That's about 5 millimeters." Then he closes the gap, nearly touching his finger to the thumb. "And that's about 0.5 millimeters." It's not a huge difference. But it could be the difference between life and death.

—David Rotman

INVESTMENT

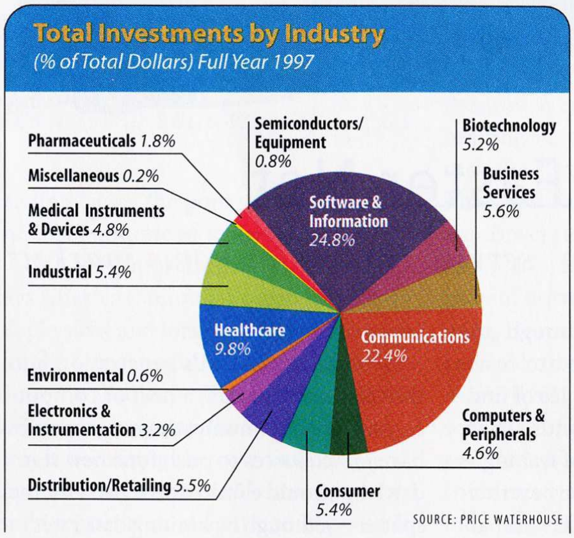
High-tech Bulls Continue Run in Venture Markets

Software and communications firms are hot

A crucial part of the U.S. innovation system is the ready availability of venture capital to back startup companies in high-tech fields. The venture markets have been roaring in recent years—pouring private money into fledgling companies. Recent data from a variety of sources show that 1997 was a banner year for new private investment, particularly in information technology companies—and that 1998 looks like another winner.

The numbers, says Pat Gray, a managing partner at Price Waterhouse, are particularly "heartening" because they point to investments in a diverse mix of businesses and for companies at different stages of development. Investment growth, he says, "was pretty broad-based, except in biotech. Software and communications hit the cover off the ball."

These optimistic sentiments are based on numbers from several sources. Price Waterhouse, the New York-based consulting firm, says venture capital investments climbed to $12.8 billion in 1997, up 34 percent from 1996. The company's numbers show that most of the money—about $8.5 billion—went to high-tech businesses, such as Internet services, software companies, and computer firms.



Other groups that track venture investments paint a similar picture. Private investments have nearly doubled during the past three years, says Rolf Selvig, director of business development at San Francisco-based VentureOne.

If private investment is a crucial part of the innovation system, so is the next step in the process: the initial public offerings (IPOs) that bring public money into the startups. And there the picture isn't quite so rosy. IPOs for venture-backed companies slowed dramatically in 1997. After a record year in 1996, the number of IPOs for startups dropped 41 percent in 1997 and the amount of money raised plummeted by 43 percent to $5.4 billion, according to VentureOne.

Regardless of the slowdown in IPO markets, there's lots of venture money available. In fact, says Clinton Harris, an investment advisor at Grove Street Advisors in Lexington, Mass., for entrepreneurs and venture capitalists, "it's a wonderful time." However, Harris raises a cautionary note. "If you're an investor it may be worrisome."

Harris believes the danger is that the success rate of venture-backed companies will drop. While the supply of money is growing, he says, "the availability of high-quality investments is not changing as quickly."

Yet because of the natural lag time in venture markets, says Harris, "if there is too much money now, it will still be two to three years before the returns drop." In the meantime, it looks as though the venture capital cog in the innovation system is turning at a high rate. **—DR**

DRUG DEVELOPMENT

Medicine Squeezes Secrets from the Grapefruit

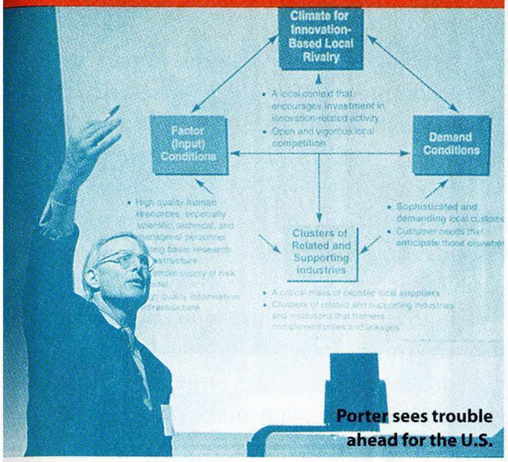
Medical researchers have known for some time that eating a grapefruit—or drinking a glass of grapefruit juice—can dramatically increase the effects of certain common drugs. But no one knew why. Now researchers at the University of Michigan in Ann Arbor, led by internist Paul B. Watkins, have identified compounds in grapefruits called furanocoumarins that explain grapefruit's mysterious power.

Furanocoumarins work by blocking an enzyme (CYP3A4) that chews up certain chemicals in the intestine—as well as some drugs. Physicians don't recommend washing down pills with grapefruit juice because the effect varies from person to person. But the discovery of the compounds responsible for grapefruit's powers could provide critical clues to increasing the absorption of drugs. And that could mean patients would need far lower doses of some extremely expensive drugs.

That's the goal of researchers at AvMax, a two-year-old biotech company in Berkeley, Calif. The company, which holds a patent on the furanocoumarins and boasts Watkins as a scientific advisor, is using furanocoumarins as a model to design ways to block the enzyme temporarily.

So far, AvMax scientists have made inhibitors of CYP3A4 and have shown in animal studies that the compounds boost absorption. They're planning a future clinical trial to test the possibility of using the enzyme blockers with protease inhibitors (medication used to treat AIDS patients). Protease inhibitors carry the hefty price tag of $12,000 a year, yet just 5 percent of the drug is absorbed.

Another goal at AvMax is to use the insight gained from furanocoumarins to convert intravenous medications. Most drugs that are given in intravenous form are not absorbed at all when given orally (indeed that's the reason they're given the painful way). If this work pans out, many fewer patients will be experiencing the pain of the needle—just one of the potential medical benefits of the humble grapefruit. **—Carol Potera**



Porter sees trouble ahead for the U.S.

DONNA COVENEY

POLICY

Indexing Innovation

Assessing the capabilities of different countries to innovate is often more art than science. But Michael E. Porter, at Harvard Business School, and Scott Stern, at MIT's Sloan School of Management, are attempting to profile innovation on a more objective footing: by the numbers. Their goal is a reproducible "innovation index." And it already holds a grim message for the United States; the country has lost its lead in "innovative potential" and is in danger of falling behind.

The analysis, being prepared for the Washington, D.C.-based Council on Competitiveness, is due out later this year. Porter and Stern create the index by determining the influence of six factors (research spending, R&D personnel, education funding, intellectual property protection, gross domestic product, and trade policies) on innovation output, as measured by the number of international patents.

The preliminary results (presented at an "Innovation Summit" held at MIT in March) show that the United States' innovation capabilities began declining in 1989. Since then, a pack of other nations have closed the gap. More troubling is the fact that—if trends continue—the United States' innovation capabilities will decline further, with a half-dozen countries racing ahead by 2006.

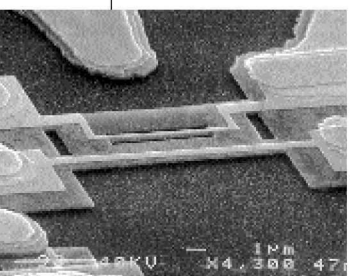
The study challenges the contention that despite cuts in R&D the United States is still technology's top dog. "Things look good today," says Porter, "but the U.S. appears to be living off its historical assets." —DR

NANOTECH

Big Money for a Small World

"Small is good" is a technology credo that is rapidly spreading throughout the world. Research on ways to exploit structures on a nanometer (billionth of a meter) scale is hot—and governments are pouring money into it. But, as with many fast-growing fields, nanotechnology is suffering from an acute identity crisis.

To better define the discipline and take its pulse around the world, a panel of nanotechnologists—funded by the National Science Foundation (NSF) and a handful of other federal agencies—has just completed a year-long tour of a who's who of U.S. and international labs. The World Technology Evaluation Center (WTEC) at Loyola College expects to release a report of the findings early this summer. "It's the first time that the whole field [of nanotechnology] has been laid out," says Richard Siegel, the panel's co-chair and a researcher at Rensselaer Polytechnic Institute.



ANDREW CLELAND/MICHAEL ROUKES

A nano-oscillator created at Caltech.

Evelyn Hu, co-chair of the panel and a physicist at the University of California, Santa Barbara's Center for Quantized Electronic Structures, says that at the beginning of the study, "I assumed that real nanotechnology was what we [electronic experts] did. But that's not true." She says the panel found nanotechnology is already making a commercial impact in applications as diverse as sunscreen lotions, catalysts, and even nanoparticles to reinforce concrete.

Nanotechnology funding continues to heat up. Spending by NSF alone reached $65 million in 1997 and is expected to climb to $70 million this year, says Michael Roco, NSF's program director. And, he says, U.S. industry is probably spending an equal amount on its own research.

The most exciting work is going on at the interface of disciplines, such as physics and biology, says Siegel. "It's becoming clear that if you use building blocks in [nanometer-scaled] regions, new things happen." The challenge, says Siegel, is "to go beyond the simple manipulation of nanostructure" and make commercial quantities of materials. Chemists and biologists are, for instance, developing self-assembling materials, including copolymers and carbon nanotubes, that could do the trick.

Still, not even nano boosters downplay the task. Single-electron devices, in particular, continue to be a growing research area for many industrial labs around the world, says Herb Goronkin, a research manager at Motorola and one of the report's co-authors. He says, however, that it is still not clear whether such devices are feasible, but, he adds, "I'm hopeful."

The uncertainty is not slowing the momentum of nanotechnology. "It's exploding worldwide," says Siegel.

And that could soon make it a very small world, indeed. —DR

MATERIALS RESEARCH

Watching Cement Dry

When he first heard a colleague talking about cement research, Ronald Berliner, a nuclear physicist at the University of Missouri-Columbia, says, "I realized with horror that I had no idea what cement was." Four years later, Berliner knows a lot about cement; in fact, he's pushing out the frontiers of what we know about this ubiquitous but little-understood substance, which is crucial in making concrete—the world's most common industrial material.

MONKMEYER/GOTTLIEB

Cement is a complex mixture; Portland cement (the type commonly used for buildings) is made mainly of silicates and aluminates, with a sprinkling of sodium, potassium, sulfur, iron, and magnesia. Scientists have long known that the ingredients combine with water to form hydrates, which bind sand and stone into concrete. Yet a rigorous chemical understanding of this process has proved elusive, because most analytical methods don't work on wet cement.

Particularly mysterious is the 6- to 8-hour "dormant" phase between the initial short period of rapid reaction, when water is first added to concrete mix, and a later period of rapid hardening. Berliner is using quasielastic neutron scattering to zero in on a key aspect of the dormant phase: the reaction of tricalcium silicate (the predominant compound in the cement mixture) with water. His work reveals that when water is added to cement, a crust forms around each cement grain. After that, it takes longer and longer for water molecules to diffuse through to the dry cement inside. That slow diffusion process accounts for the mysterious dormant phase.

Berliner is hoping that knowing precisely how the tricalcium silicate and water molecules combine will lead to ways to optimize the reaction, yielding stronger, more durable concrete. And even small improvements could yield tremendous savings, because so much concrete—350 million metric tons—is made every year around the world.

What's more, improving the strength of concrete could reduce the volume required in structures, which would be good news for the environment. Cement manufacturing is a major culprit in global warming; an estimated 10 percent of the greenhouse gases generated by human activity are formed in cement production, which also uses an estimated 3 percent of the U.S. electrical generation capacity.

Berliner is now using neutron scattering techniques to attack the "concrete plague" that is causing the rapid deterioration of many roads and bridges. Finding a cure would make watching cement dry a lot more interesting than it might initially seem.

—Deborah Kreuze

Moonlight over Academeme

I'M TIRED OF THE WHINING ABOUT INNOVATION. Tired of hearing ossified academics and weary policy-meisters chronicle the decimation of corporate support for "pure" research. Tired of doomsday rhetoric that predicts the imminent demise of American technology. Tired of industrial ostriches complaining about the "short-term" focus of such high-tech pacesetters as Intel, Microsoft, and Sun.

Let's face it: The naysayers are dead wrong. Slicing billions of dollars from corporate laboratories hasn't made a dent in U.S. competitiveness. Indeed, from AT&T to IBM to Xerox, American industry is healthier because it has slimmed down its bloated and centralized research staffs. Across the spectrum of information technologies—from the Web to chips to software—U.S. ingenuity reigns supreme. Ditto for agrotechnology, aerospace, materials, and telecommunications. Only in biotechnology and pharmaceuticals does the United States have foreign rivals with deep pockets backed by first-class research.

Basic researchers are playing a growing role in corporate innovation—as moonlighters on specific projects.

This reemergence of American dominance has been led not by the national government and not by whole sectors of industry but by individual companies. To paraphrase the language of historian Thomas Hughes, we live in a time when individual companies are "transcendent": They define the terms on which industry after industry operates.

But if individual firms reign supreme, and those same firms are trimming their research establishments, does fundamental research have any role in the resurgence we're seeing? Absolutely. The irony is that, far from being banished from the corporate tent by cutbacks, serious researchers are playing a *growing* role in innovation at the level of individual firms. The explanation for this apparent paradox is that innovative companies aren't looking for full-time scientists; they want moonlighting academics, professors willing to work on specific projects for often-lucrative piece rates.

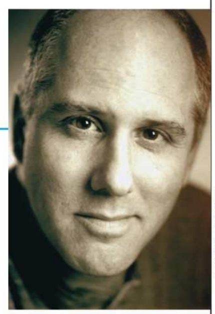
"There's almost no company that I'm aware of that doesn't have heavy involvement from professors," says Michael Crow, who oversees research and development at Columbia University. "Professors are playing a much more significant role than 25 years ago in firm-level innovation."

Consider Barbara Hayes-Roth, a cognitive scientist at Stanford University who is a world leader in creating "intelligent agents," or digital characters, for interactive media. The characters can carry on conversations and offer advice, playing off key words, pattern recognition, and their own "knowledge" of the world they inhabit.

When Hayes-Roth began her research a decade ago, interactive media was in its infancy and the Web—where most of her characters reside—didn't even exist. But her research interests drew the support of the Advanced Research Projects Agency and a host of corporations; over time the commercial relevance of her work became overwhelming. For years she stood firm, limiting her consulting and some years confining her work to academia. Last year, she decided to scale back her duties at Stanford and devote more time to a company she's launched to commercialize intelligent agent software.

The shift came easily, she says. "In academia, you're already a kind of entrepreneur. You're creating ideas and bringing in the resources to make your research possible." The only difference, she adds, is that "in the university, we sell our idea *before* we make it and outside we sell it *after* we make it."

This alliance of industry and academia would seem to bring wide benefits, yet it's deeply troubling to people wedded to older models of how universities should interact with the private sector. And to be sure, there are at least two big dangers in the industry's growing reliance on professors.



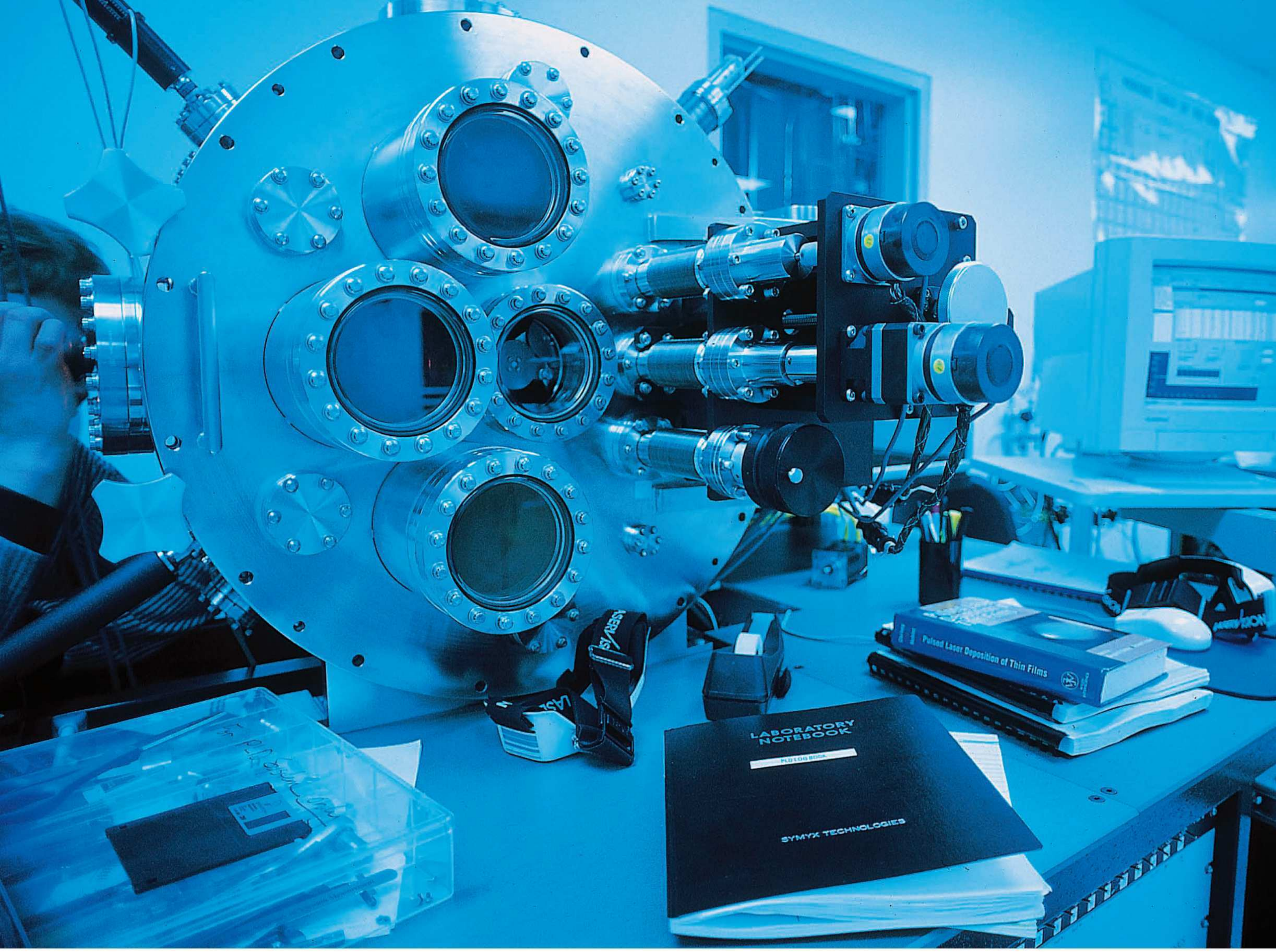
DAVID ZADIG

As they become more profit-driven, academics threaten to undermine one of the hallmarks of a liberal education: the largely unfettered exchange of ideas. While intellectual property claims remain the exception rather than the rule, it isn't absurd to imagine that, at least in some scientific and technical fields, one professor will have to pay a royalty simply to read another's *published* findings.

Then there's industry's emphasis on technologies that are fast and cheap. If one thing separates university researchers from those in corporations, it's the academic's insistence on pursuing solutions that are interesting—without regard to efficiency. "I always like to see a research project hung on a problem, but then I don't like to see any constraints on how the problem is pursued," says Michael Lynch, an applied mathematician at the U.K.'s University of Cambridge. Even though Lynch has formed two successful software companies while a professor, he worries about the tendency of academics to become midwives to industry. "The danger is that we kill the golden goose because we ask it to lay too many eggs," he says.

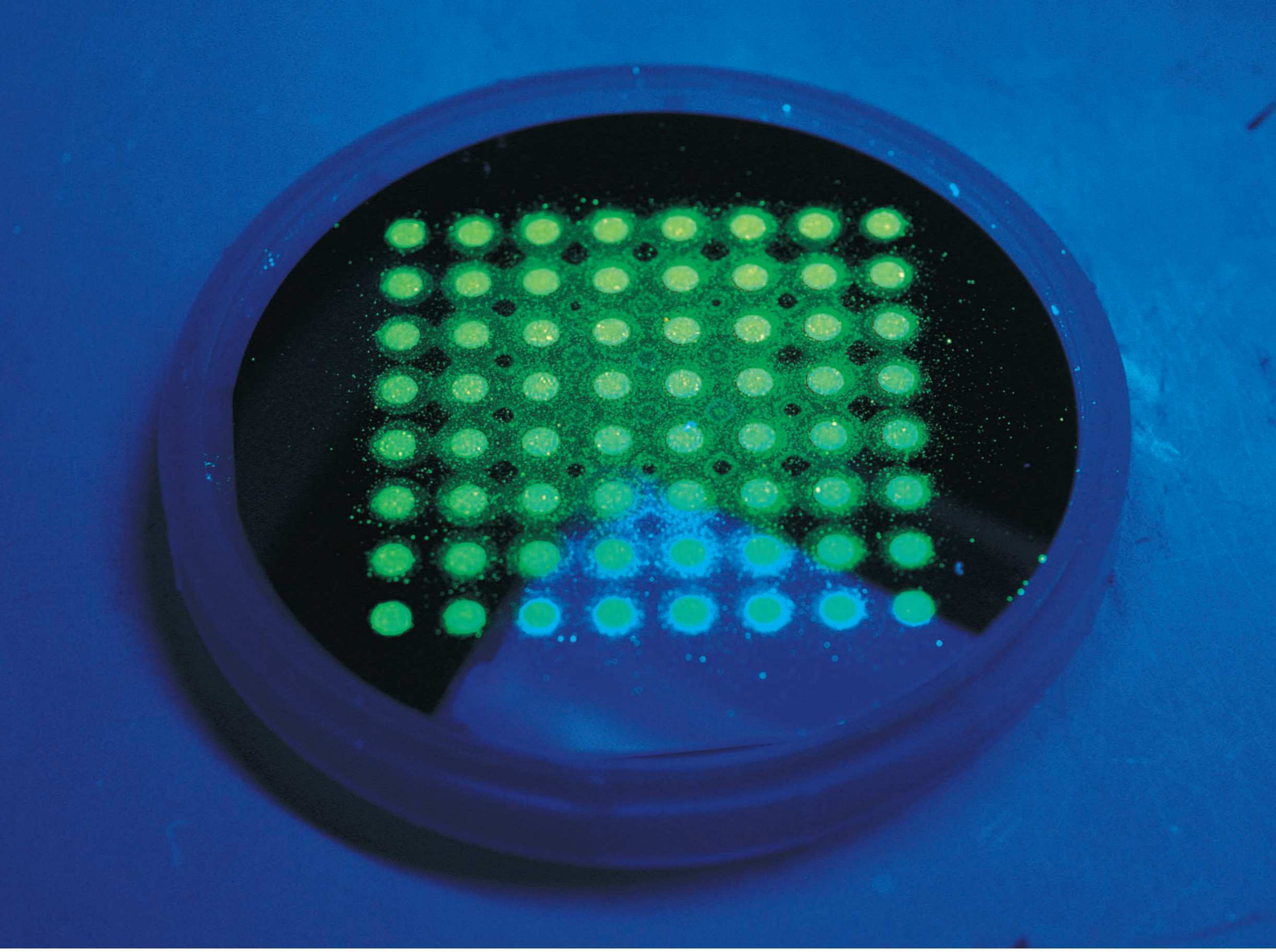
These concerns are quite real, but the fact is that the Ivory Tower has fallen, and its pieces, like Humpty Dumpty's, can't be put back together again in the same way.

Just ask Craig Barret. In the early 1970s Barret was a rising star at Stanford, a PhD in materials science. One summer Intel came knocking, asking for a student to help sift through a problem with the ceramic packaging around one of the company's new chips. On a lark, Barret offered himself. He quickly solved the problem and was hooked. Recently, he was named Intel's CEO, succeeding Andrew Grove.



Winning Combination

Combinatorial chemistry, with its high-speed, automated methods, is all the rage in drug research. Can it repeat its success in the search for new materials?



High-tech bingo: Inside a vacuum chamber (left), Symyx synthesizes ordered arrays of inorganic compounds (above). Any one could be paydirt.

By Robert F. Service

In a modest, two-story office building in the heart of Silicon Valley, a series of experiments that could change forever how scientists hunt for new materials is taking place. In one lab, a robotic arm sealed within a tabletop-sized vacuum chamber is intent on synthesizing electronic compounds. The robot selects a ceramic wafer from what looks like a small stack of compact discs and draws the wafer to a central chamber a foot away. A beam of electrons blasts the disc, blowing ceramic vapor against tiny squares on a shiny silicon wafer. Shutters inside the vacuum chamber click open

PHOTOGRAPHS BY WILLIAM MERCER MCLEOD

and closed to control precisely how much of the vapor hits each square. The robot puts the first ceramic disc away and selects another. The process is repeated until the silvery wafer is coated with dark squares, each a potential new high-temperature superconductor.

Down the hall, another diminutive robotic arm whisks back and forth across a benchtop. The arm's needle-shaped tip squirts a few drops into dozens of wells positioned in a plastic tray the size of a paperback book. Each well holds a different mix of chemicals and, before long, each will contain a type of plastic never made before. One of those novel polymers could become a choice material for high-strength structures, electrical insulation, or biological implants.

Welcome to the headquarters of a startup called Symyx—and perhaps to the future of materials prospecting. In this new strategy, borrowed from chemistry and biotechnology, automated machines rapidly synthesize and sift through anywhere from dozens to tens of thousands of novel materials in hopes of hitting pay dirt. It is a big change from how materials scientists have traditionally worked, following precise recipes—and occasional spurts of inspiration—to mix chemicals in test tubes tediously cooking up new materials one at a time.

The mass-production approach to discovering new materials, known as combinatorial chemistry, systematically mixes a handful of chemical building blocks in all possible combinations to create an array of compounds in the time it used to take researchers to make just one. The shotgun method works because researchers can then—at least according to theory—rapidly screen all the compounds in the array. If one of the compounds shows hints of being useful, researchers can quickly pluck it out of the vast lineup.

Combinatorial chemistry has already transformed the fields of drug discovery and genetic screening, turning the search for new compounds from a plodding one-at-a-time business to a high-tech bingo game. Combinatorial companies, such as Affymax and Pharmacopeia, which were formed to apply the technology to drug discovery, have become some of biotech's best-known success stories of the 1990s. Now, researchers at Symyx—and several other labs scattered around the country—are looking to do the same thing for the materials world. "We're in the early stages of running a very exciting experiment," says Symyx's scientific director Henry Weinberg.

The stakes could hardly be higher. In addition to polymers and superconductors, Symyx's robots are turning out collections of catalysts and light-emitting materials. If any of the compounds pan out, Symyx stands to strike it rich. The discovery of, say, a hot new industrial catalyst that is capable of reducing production costs of a commodity plastic could be worth millions, allowing manufacturers to gain an edge in multibillion-dollar markets.

Investors have noticed. Biotech entrepreneur Alejandro Zaffaroni and University of California, Berkeley, chemist Peter Schultz cofounded Symyx in 1995, raising $1 million and hiring two full-time employees. Today, the company has more than $75 million in private backing and research deals. In 1997 alone, it grew from a staff of 23 to 85 scientists and now boasts seven combinatorial chemistry labs. Several others have initiated programs, and now some of the big chemical companies are jumping into the game (*see sidebar on page 38*).

This interest has been whetted by early signs of success. Last fall, Weinberg and his colleagues reported that they had made and screened a library of more than 25,000 different phosphors (light-emitting materials widely used in television screens to convert electricity to different colors).

His own angle of vision: Symyx scientific director Henry Weinberg.

Playing for Material Gain

COMPANY	BACKING	STRATEGY
ArQule *Medford, Mass.*	Initial public offering in Oct. '96: collaborations with pharmaceuticals and biotech companies.	Proprietary technology for finding new drugs and agricultural chemicals. Research program exploring catalysts and polymers.
SRI International *Menlo Park, Calif.*	A not-for-profit think tank with more than $300 million in revenues.	Developing applications for discovering catalysts, lubricants, and coatings.
Symyx *Sunnyvale, Calif.*	Venture groups; research agreement with Hoechst.	Combinatorial techniques for finding new materials, including superconductors, phosphors.

PHOTOGRAPHS BY WILLIAM MERCER MCLEOD

Several months ago, the Symyx team reported finding a remarkable new blue phosphor composed of strontium, cerium, and oxygen that has an atomic structure completely different from other phosphors. The new phosphor is comparable to the brightest blue phosphors on the market, and the Symyx team has already begun to explore new variants of the structure to look for improvements. "This shows one can discover unexpected materials with combinatorial methods," says Weinberg.

The stakes could hardly be higher—if any of the compounds pans out, Symyx stands to strike it rich. A new catalyst could be worth millions.

Taking a Clue from Nature

Though weinberg and his colleagues at Symyx are the first to try to commercially apply combinatorial techniques to materials research, they didn't invent the process. In fact, they were beaten out by a few billion years by a very creative innovator: Evolution. Cells have the ability to create a wide variety of molecules based on a limited number of building blocks and then select the ones that function best. In this familiar evolutionary process, cells create an enormous variety of DNA and protein molecules by arranging common building blocks in a different order. Natural selection does the rest.

Beginning in the early 1980s, researchers began imitating nature's example. They started creating collections of peptides—short proteins that can bind to cell receptors and thereby regulate cell function. Just how well this regulation takes place depends on how tightly a peptide binds to a receptor, which itself depends on getting just the right sequence of peptide building blocks, amino acids. Researchers invented several methods that made it possible to arrange amino acids in different combinations and track the products they made. They found that they could easily create thousands of peptides in nothing flat. By testing these compounds for activity in cells, researchers could quickly home in on the most chemically active peptide and work out its structure.

These early successes didn't win many converts among those who design new therapeutic drugs for a living. "There was enormous resistance from medicinal chemists in the beginning," says Joseph Hogan, founder and chief scientific officer of ArQule—a Medford, Mass.-based combinatorial startup. "They felt it was completely inelegant and ugly" compared with the traditional approach of rationally designing and then painstakingly synthesizing compounds.

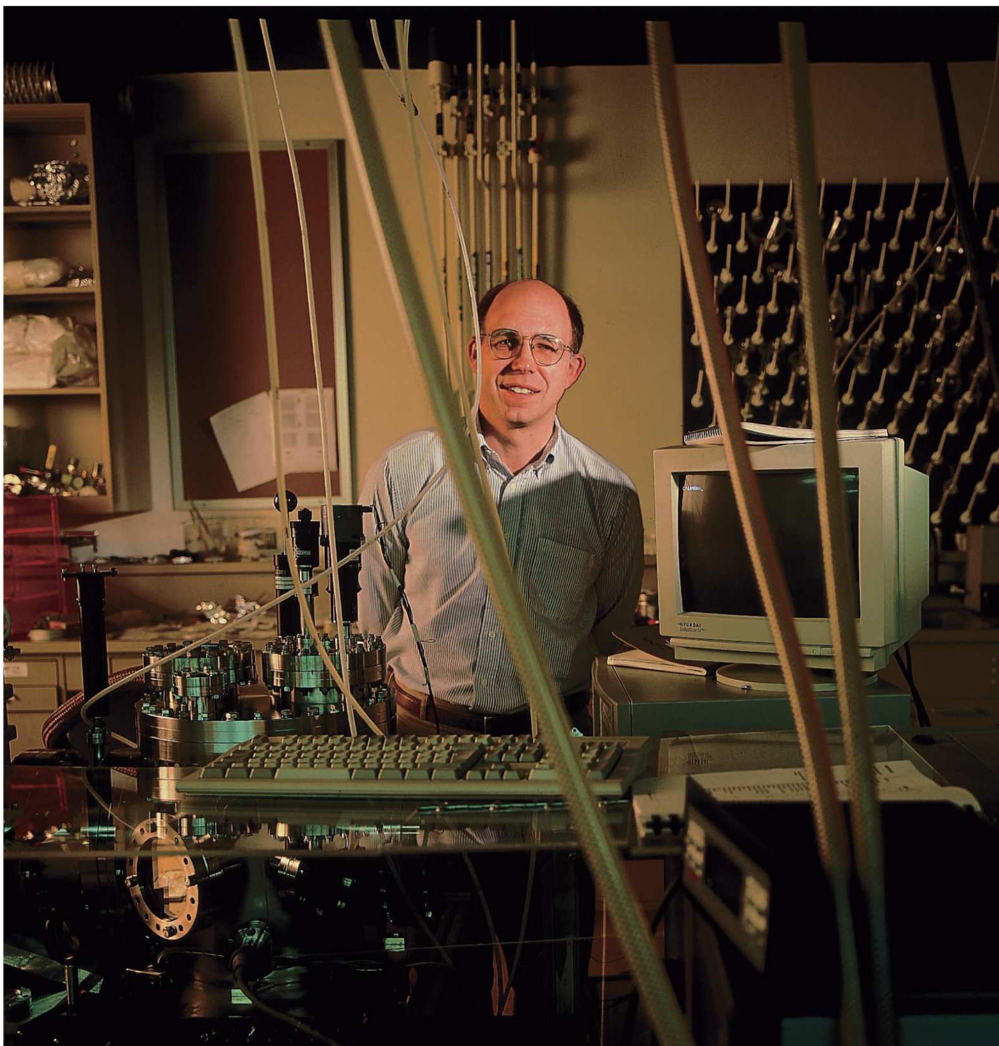
The approach also faced practical limitations. Because enzymes in the stomach break down peptides, most researchers considered them poor drugs. But the idea was in the air, and before long, new research teams showed that the basic strategy could go beyond peptides and turn out small organic compounds similar to those that make up most drugs.

By the beginning of the 1990s the craze for high-speed chemistry was sweeping through the pharmaceutical industry. Startups sprang to life to commercialize combinatorial know-how. Flush with hundreds of millions of dollars from investors, these companies set about creating libraries of potential drugs with as many compounds as big pharmaceutical companies had hoarded on their stockroom shelves during the past 100 years. Not to be left out, Big Pharma companies, such as Glaxo Wellcome and Merck, leaped into the fray starting their own combinatorial research efforts and striking deals with combinatorial chemistry startups. "In the mid-1980s, traditionalists were laughing at the idea of the combinatorial synthesis of drugs," says Weinberg. "But they're not laughing now."

Back to the Future

Schultz is betting that for materials science, the present is like the late 1980s all over again. In 1995, Schultz—a Berkeley chemist who holds a joint position at the Lawrence Berkeley

Early combinatorial explorer: Berkeley's Schultz is now looking for new materials.



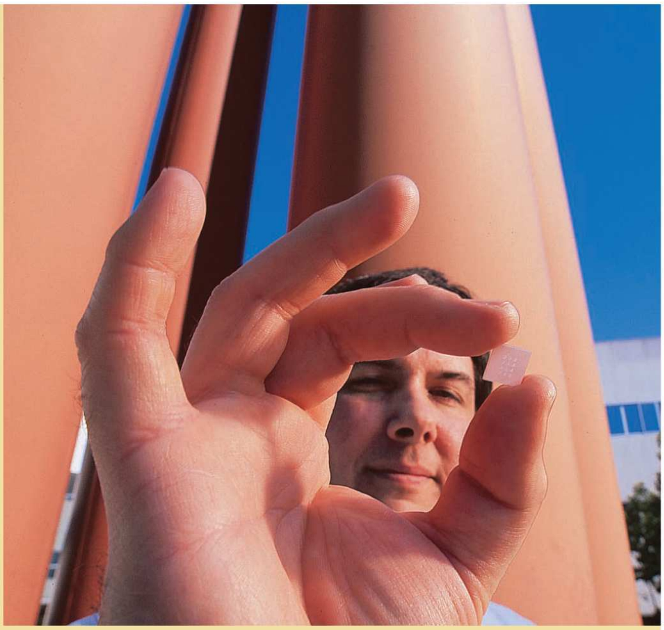
The Chemical Giants Choose to Wait and See

While symyx was the first to jump wholeheartedly into the combinatorial materials business, several others are testing the water. ArQule—a Medford, Mass.-based startup that had focused on combinatorial drug discovery—and SRI International—the Menlo Park, Calif. research and consulting group—recently launched combinatorial materials programs.

But it was the decision last year by Germany's Hoechst, one of the world's largest chemical makers, to back Symyx with $43 million over five years that signaled the technology's entry into mainstream industrial research. Materials powerhouses DuPont, Lucent Technologies, and Eastman Kodak are setting up combinatorial research programs. Still others, including Dow Chemical and Engelhard, a New Jersey-based catalyst producer, are watching closely to see whether they should get in the game.

Even if Symyx—or its competitors—does not immediately strike a mother lode, combinatorial chemistry could transform the search for new materials in the same way it has revolutionized drug discovery. Finding drug candidates was long dominated by large pharmaceutical companies, which had the money and patience to painstakingly synthesize compounds one by one. The development of combinatorial tools meant suddenly venture-backed companies could turn out as many drug leads as the big drug houses; as a result, they have stolen much of the front-end business of research—the actual discovery of new drug leads.

New materials are still largely discovered by big companies. "When looking for compounds one at a time the big companies win because they have bigger labs," says Symyx's scientific director Henry Weinberg. But Symyx says it can turn out more compounds in a month than a large corporate lab does in a year. That could open the door for a whole new crop of "chemitech" startups. Like their biotech predecessors, chemitech companies could begin to take over the early stage of the discovery process.



Small packages—good things: SRI's Schneider and ArQule's Hogan (below) think combinatorial methods are the wave of the future.

Many industrial researchers remain cautious, however, pointing out that there is a vast difference between discovering drugs and discovering materials. Synthesizing pure compounds, determining structure, and picking winners from losers are all harder with materials, such as polymers and catalysts, than with drugs, says Kris Krishnamurthy, a chemist with Eastman Kodak. Combinatorial materials research "has a potential that must be investigated," says Krishnamurthy. But most companies, he says, are taking a wait-and-see approach.

"The chemical and materials industries typically do not have the same risks and rewards as drug companies," says Patricia Watson, who heads DuPont's combinatorial materials group. In pharmaceutical research, the strategy of bet big/win big works because if you come up with a new life-saving heart drug, patients will pay a premium for it. "There isn't the same payoff in the chemical and materials business," says Watson. Charge too much for a new non-stick cooking surface, and manufacturers will stay with Teflon.

But though the method is still not commercial and some of the big chemical companies remain on the sidelines, SRI's Luke Schneider doubts caution will win the day. He suggests that combinatorial chemistry will make its mark sooner than many anticipate.

Indeed, combinatorial chemistry startups are betting it's only a matter of time. "I have no doubts at all that this [transition] will happen," says Joseph Hogan, founder and chief scientific officer of ArQule. "The old paradigm is completely breaking down," he adds. "This has completely changed how chemistry is done."

PHOTOGRAPH ABOVE BY WILLIAM MERCER MCLEOD, BELOW BY JAY REED

National Laboratory (LBNL)—teamed up with LBNL physicist Xiao Dong Xiang and others to create a combinatorial library of materials rather than drug candiates. The group first made arrays of 128 different compounds, each a potential high-temperature superconductor, and each a tiny speck just 200 millionths of a meter across. The Berkeley team and others went on to create libraries of phosphors, data storage materials, polymers, catalysts, and even electronic devices.

For all these diverse materials, the basic strategy is the same: Make a lot of compounds at once, then scan them simultaneously to see which works best. To make the superconductor array, for instance, the Berkeley team sprayed seven different inorganic oxides one at a time through a mask. By using a series of different masks to control the deposition of each oxide, the researchers created a checkerboard of compounds in which each 200-micron square on the board contained a different combination of elements. The entire chip was then processed and screened for activity.

But making such arrays turns out to be the easy part; it's much harder to pick winners. "It doesn't make a lot of difference if you can make 100,000 compounds at once if you still have to test them one by one," says Brandeis University chemist Gregory Petsko, who is also a scientific adviser to ArQule. Rapid screening methods are widely available in drug discovery research to detect desired biological activity. But equivalent screens for measuring most physical properties, such as flexibility and electrical conductivity, simply don't exist yet.

"How do you measure the strength of a nanogram of material?" asks Luke Schneider, who heads the combinatorial effort at SRI International, a consulting and research firm in Menlo Park, Calif. "Nobody has developed that technology yet." Further, combinatorial approaches require measurements of thousands of compounds at once. "There's a whole new technology that has to be built," says Schneider.

Several groups are trying to develop convenient methods for rapidly testing the properties of huge batches of different materials. Symyx found its new blue phosphor earlier this year by simply shining ultraviolet light on an array of candidate phosphors to see which glowed the brightest. Other high-speed screens are in the works. Last year, Xiang and his LBNL colleagues invented a new high-speed scanning microscope that they use to screen arrays for electronic properties. Richard Wilson and his colleagues at the University of Houston have been experimenting with an infrared sensor for tracking the activity of arrays of catalysts by looking at the heat given off during reactions.

Although the hunt is on for new screens, most of the success in developing combinatorial materials has come in designing libraries of interesting new compounds. Recently, the Berkeley team staked out more new territory by reporting the first combinatorial array of electronic devices. In this case, the researchers made simple devices called ferroelectric capacitors, used to store information as packets of electrical charge on DRAM (dynamic random access memory) computer chips. Computer companies hope to shrink DRAM chips to even smaller dimensions. But the materials currently used to confine the electrical charge fail when they're layered too thin, causing current to seep out like water from a leaky bucket.

To find new "buckets" that don't leak as much, Xiang and co-workers built an array of several thousand capacitors, each with a charge-confining layer made of a slightly different ceramic alloy. The group found that a particular combination of barium, strontium, and titanium, spiked with a touch of tungsten, was the best yet at stopping the leak. The new material is not likely to find its way into devices immediately because it still must prove itself on other grounds, such as fitting in with current chip-making practices. But it offers a promising new lead.

Though capacitors and phosphors are tempting targets for these revolutionary combinatorial methods, the big payoff

Making the Right Stuff

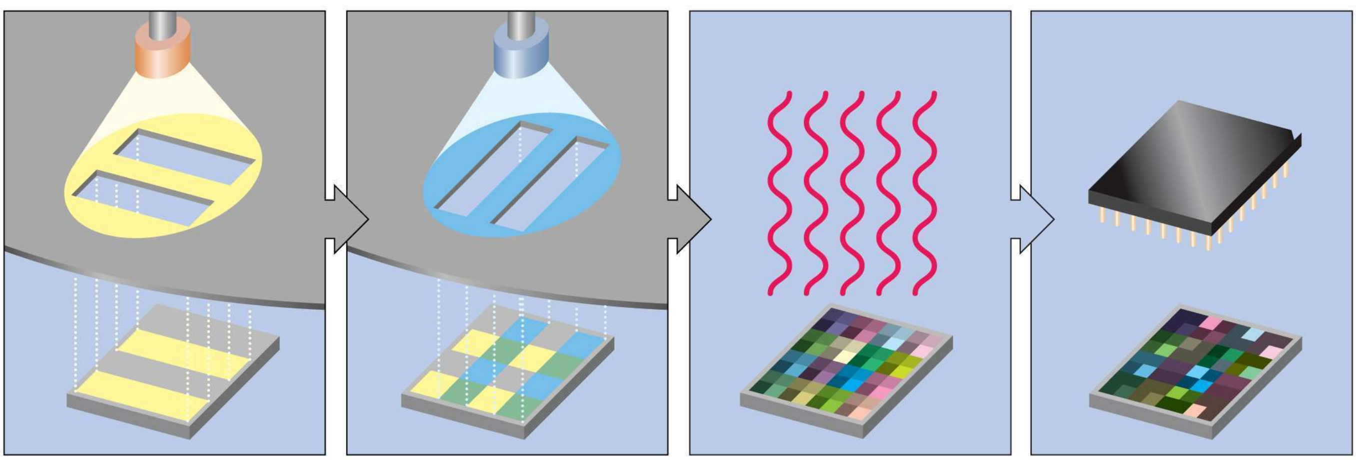
Combinatorial materials science is adept at making complex inorganic compounds and—in theory—picking out the most promising ones.

One version of the technology, as practiced by Symyx, makes arrays of different inorganic materials by spraying a number of compounds on a chip inside a vacuum chamber.

Using a series of sprays and stencils, Symyx controls how much of, and where, each compound is deposited: Each square in the array will be a slightly different material.

The chip is processed. Various methods are used, including heating and exposure to high pressures. The goal is to react the chemicals in each square, forming a stable compound.

Detection methods depend on the materials and applications. But the idea is the same: Rapidly sample each square independently looking for some identifying—and desirable—property.



BEN BARBANTE

could prove to be catalysts. Catalysts are key to a myriad of commercial processes, ranging from plastic manufacturing to the production of high-volume chemicals to emission-control devices in cars. Come up with a catalyst to make a better—or cheaper—commodity plastic, and you stand to win big. "You can warp markets with those things," says Hogan.

Despite the economic incentives, researchers have a tough time designing catalysts. Catalysis is a notoriously complex process, and catalysts are finicky creatures; each works best under its own set of conditions, such as temperature, pressure, and concentrations of reactants. Figuring out how these variables affect the catalyst is extraordinarily difficult. As a result, polymer chemistry has long been part science and part art, with chemists relying heavily on intuition—and sheer luck—to find new catalysts. "Nobody knows how to design the ideal catalyst from scratch," says Petsko.

The complexity of the materials makes discovering new catalysts a prime testing ground for combinatorial chemists. In 1996, researchers led by Amir Hoyveda

Following the Science

Where alejandro zaffaroni roams, money seems to follow. A drug and biotech entrepreneur since the 1960s, Zaffaroni has achieved a winning streak that is almost unprecedented in that high-risk business. Over the past decade, he bet heavily on combinatorial chemistry to power drug discovery—and won. So when Zaffaroni started up Symyx in 1995, offering up a vision of a combinatorial materials world, investors listened.

"If Zaffaroni was not backing it, Symyx would not have the momentum it does now," says Xiao Dong Xiang, a physicist at Lawrence Berkeley National Laboratory who pioneered many of the techniques used by Symyx. "People trust him and trust his record," he says. And why not, says University of Maryland physicist T. Venkatesan. "He's got the Midas touch."

That touch has a lot to do with a keen feel for the potential of basic research—and the foresight to join forces with cutting-edge researchers. In 1987, Zaffaroni sought out Peter Schultz, a biochemist at the University of California, Berkeley, to learn more about his pioneering work on antibodies capable of catalyzing chemical reactions. Schultz was taking advantage of the immune system's ability to create a wide variety of antibodies, select the best, and then make innumerable copies.

While the work clearly represented a significant advance in scientific understanding, Schultz says he had little sense of its commercial implications. Zaffaroni, however, was intrigued and wondered whether the shotgun approach could be used to discover potential pharmaceutical compounds by rapidly synthesizing and screening different molecules.

"We talked about the idea of forming a company," says Schultz, who says he had no idea of Zaffaroni's track record as a biotech entrepreneur. "I asked him naively if he had a source of funding, and he handed me his curriculum vitae." says Schultz.

The rest is venture-capital history. In 1989 Zaffaroni founded Affymax, the first company devoted solely to using combinatorial chemistry to discover new drugs. In 1993, that company spun off Affymetrix, which applied combinatorial methods to creating DNA chips for genetic screening. Two years later, with the combinatorial revolution spreading through the drug industry like wildfire, U.K.-based Glaxo shelled out $538 million for Affymax. And last year Zaffaroni spun off another firm, Maxygen, which plans to use a related combinatorial approach to create novel DNA-based vaccines.

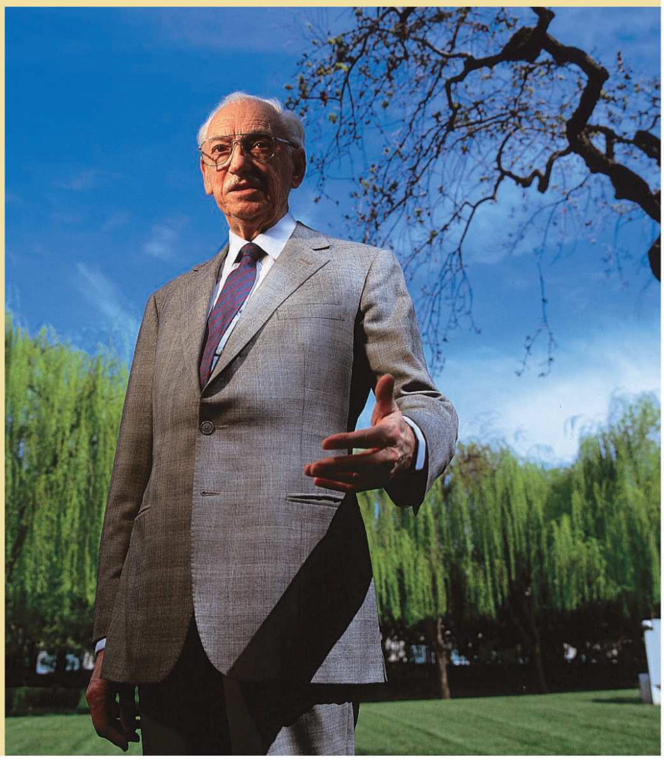
In the midst of this combinatorial boom in drug discovery, Schultz became convinced that the high-speed technique could trigger a similar revolution in materials discovery. Zaffaroni was not sure, but he wasn't about to balk at the instincts of his longtime associate. Schultz recruited Xiang and a handful of others and quickly turned out a combinatorial library of 128 potential high-temperature superconductors on a one-inch chip. That was enough for Zaffaroni.

"He's not a materials scientist," says Schultz. "But he is a person who is always looking for new scientific ideas. When he sees something with tremendous potential, he's not afraid to go after it. It's just damn the torpedoes, full speed ahead. But he [makes the commitment] with a lot of scientific insight and careful analysis."

Scientific insight comes naturally to Zaffaroni, who has a PhD in biochemistry from the University of Rochester. But there's another quality that may be equally important to his success: the willingness to wait.

"If I believe in a concept, I have tremendous patience," he says. After all, he adds, 98 percent of research results are negative results. "You have to create a broad spectrum of opportunities, because you don't know where success will come from." The next few years should tell whether this philosophy has been justified again—in the world of combinatorial materials.

A Midas touch: Will Zaffaroni's magic extend to materials?



PHOTOGRAPHS BY WILLIAM MERCER MCLEOD

and Marc Snapper at Boston College turned in one of the first reports on creating libraries of different catalysts. And now just about everybody else, including Symyx, ArQule, SRI, and DuPont are trying to do the same thing.

Still Obstacles

Despite the progress, combinatorial chemistry still must prove itself in materials research. And while combinatorial methods went from scientific oddity to rising star in the drug business within several years, success in the materials industry could be tougher to achieve.

Fast screening, it turns out, is not the only headache. Researchers must also come up with faster methods for determining the exact molecular structure of each compound. That is particularly difficult for crystalline materials such as high-temperature superconductors, says Xiang. Even if scientists know the exact chemical composition of a square in the array, the material can adopt a variety of structures, in the same way that precipitation can come down as rain, hail, or snow.

Scanning the chessboard: LBNL's Xiang is betting scanning microscopes will find the winners.

And beyond such research hurdles loom even more daunting commercialization challenges. "Finding a good material is not enough," says Xiang. Researchers must figure out how to scale-up production from nanograms to tons. Even if a substance can be produced in relatively large quantities, bulk materials often behave very differently than do thin films. A compound that acts as a high-temperature superconductor when it is a thin film can behave completely differently as a bulk powder. "There are a lot of just plain doubters who question [whether] all this can be done," says Bob Ezzell, a chemist at Dow Chemical.

Many don't want to take the risk. "Most research managers with budget responsibilities don't want to take a gamble" on an unproved technology, says Gerald Koermer, a chemist at Engelhard. "Their tendency is to hold back."

But combinatorial proponents are not daunted. The technology, says SRI's Schneider, escalates the research arms race, allowing its users to come up with new products faster and cheaper than competitors. And in a business where winners and losers are often determined in patent court, combinatorial chemistry could allow companies to sew up rights to new technologies before other companies even get wind of an emerging field, says Schneider. In an initial patent "it's very difficult to cover everything you would like to cover," Schneider explains. By speeding up the discovery process, he says, "combinatorial chemistry allows you to cover more of the world."

The process also works in reverse. "It also makes it easier for your competitor to get around your technology," by allowing them to quickly explore hundreds or thousands of alternative compounds to one already on the market, says Schneider. As a result, Schneider believes that in the near future, chemicals and materials companies will be more or less forced to use combinatorial efforts to prevent competitors from pirating their core businesses.

Some think companies will be forced to use combinatorial techniques—to prevent competitors from pirating their core materials business.

Just when that will happen is anybody's guess. And it will take a radical change in thinking. "Research really hasn't changed much since Madame Curie," says Schneider. Combinatorial chemistry, he adds, "represents a major change in the research mindset. Making that change is hard to get people to do." For researchers to be convinced that combinatorial chemistry is the wave of the future for materials science and not just a passing swell, "it's really going to take a hit," says Schneider. But if and when someone gets that first big hit, he says, "everyone will follow and say, 'God, I can't believe we haven't been doing this all along.'"

Field Work in the Tribal Office

Photographs by Anne Hamersky

Docudrama: David Levy, Jeanette Blomberg, and Randy Trigg of Xerox PARC observe California state transportation engineers working with construction documents.

At Xerox's famed Palo Alto Research Center anthropology teams help innovate by watching how people *really* work

BY ROBERT BUDERI

IT'S A MOVIE CLASSIC—BUT NOT ONE you'll find on late-night television. The short film opens with a scene from "9 to 5." Jane Fonda's character arrives for her first day of work. Cold-hearted boss Lily Tomlin guides her to the Xerox room, fires off the incomprehensible instructions for operating a monstrous copier, then leaves an overwhelmed Jane to her own devices.

The scene shifts to real life: a time-lapse videotape of two men in jeans trying to make double-sided copies with a state-of-the-art Xerox copier. In growing frustration, the pair huddle repeatedly to scrutinize the instructions while a mountain of single-sided copies rises nearby. After an hour, they're defeated. One of the pair sighs: "We're S-O-L."

When this video made its debut before an audience of top Xerox managers, one executive scoffed at the technologically incompetent subjects. "You must have got these guys off the loading dock," he said. That was a perfect setup for the bombshell: Both men were computer scientists filmed

at Xerox's famed Palo Alto Research Center (PARC). One was well-known computational linguist Ron Kaplan. The other was Allen Newell, a founding father of artificial intelligence.

The film of these two big brains trying to operate a copier hardly ranks as a Hollywood blockbuster. But it's had a big impact on Xerox. Dubbed "When User Hits Machine," it was presented to various high-level management groups in 1982 by a mid-level PARC lab manager named John Seely Brown. It showed clearly—as did a second, far-less-lighthearted tape of researchers trying to use Xerox's new 8200 copier—the daunting problem of making any technology truly user friendly.

And it marked one of the first efforts of a unique PARC group dedicated to overcoming that barrier: a cadre of academically trained anthropologists who spend their time studying how people interact with machines, and with each other, as information flows through the workplace. John Seely Brown, or JSB as he's widely known, has since risen to become the director of PARC, as well as Xerox's chief scientist. Under his aegis, the anthropology group has grown to include about a half-dozen people who stalk the halls of government and business as if they were deep in the African bush observing the customs of a strange tribe.

Joined by colleagues in computer science and other disciplines, Xerox anthropologists have gone into the field to conduct extensive workplace studies of such groups as the company's service reps, airline operations personnel, attorneys, and civil engineers. Their growing understanding of the nature of these jobs has allowed them to write scientific papers on the often-overlooked but important ways knowledge is informally created and shared in the office, while also providing fodder for design of novel technologies to make work easier. Already these exotic and seemingly fuzzy pursuits have paid millions in demonstrable benefits to Xerox and its customers, an indication that PARC has a unique approach to innovation that foretells even bigger dividends down the road.

RECOVERING THE FUMBLE

PARC IS THE PLACE INFAMOUS FOR "fumbling the future," as the catchphrase goes. Back in the 1970s, it was the home of a remarkable suite of creations: the digital mouse, the graphical user interface, the laser printer, and the Ethernet, among others—just about the entire infrastructure of the modern office. Yet many of these inventions wound up being commercialized by firms other than Xerox.

Since taking over in 1990, Brown has worked hard to avoid repeating past mistakes by shifting the lab's orientation from invention to innovation, which he defines as "invention implemented." This approach extends far beyond merely creating something new to helping it reach the market. In his view, innovation also involves probing the very nature of work, recognizing that technologies will shape work practices—and that those shifting work customs, in turn, reshape technology. While still a small part of what PARC does, the anthropology work gets at this feedback cycle and reflects the new spirit as few other pursuits do.

Cascading down the sun-soaked California hills, PARC today crackles with big ideas. Home to roughly 250 scientific and technical staff, its offices and labs are interspersed with pleasant lounges to allow informal get-togethers and brainstorming sessions. Descending through the complex's steep concrete staircases to the various sections, or pods, a visitor finds experts in smart machines or electronic commerce, and display screens made of lightweight and inexpensive organic materials. You can also see the lab where PARC researchers grabbed headlines last October by generating a blue diode laser beam that one day might enable computer printers to match the resolution of the best traditional printing technologies. The anthropology group lives down in a corner "pod" on the first level.

The role of the anthropology group is to help Xerox understand today's workplace, a complex knowledge environment in which information is transferred from subgroup to subgroup as tasks get done. In this structure, individuals play varying roles—sometimes boss, for example, sometimes employee—and the subgroups themselves have subtly shifting connections. "For an anthropologist," PARC researcher Julian E. Orr once wrote, the corporate environment "is oddly reminiscent of the oppositions within segmenting lineages of the Nuer or the Afghans, or of the *nisba*, an infinitely branching Moroccan system of personal identification." The kicker for Xerox is that in today's office, such structures mediate the flow of information—and that's where Xerox makes its living.

Anthropologists have been part of PARC's staff since 1979, when Lucy Suchman arrived from the University of California to study everyday life in a big company. A down-to-earth type who feels people are too often painted with a broad brush, Suchman questioned the computer scientists' assumption that office work was so straightforward and procedural that it should be tailor-made for computerization. To prove her point, she began studying the most seemingly procedural group she could find: accounting.

The way a computer scientist might view this job, a customer sends in an order, paperwork is processed, and the goods are shipped—providing a perfect opportunity to improve efficiency by automating processing chores. But Suchman's investigation showed that clerks really did many tasks in parallel, rather than in a linear fashion. For instance, a customer might phone in his order, assuring the clerk the paperwork was on its way. To help the customer, the goods would then be shipped before all the forms had been completed. Says Suchman: "In the end the record will have all the necessary paperwork. But if you just in a unilateral way insisted on doing things according to the rules, you would actually make your customers very unhappy, and it would be an inefficient way of doing business."

Suchman cast her findings as fitting into a small movement already under way at PARC to shift research from an office automation viewpoint to the wider perspective of the "knowledge worker." The basic

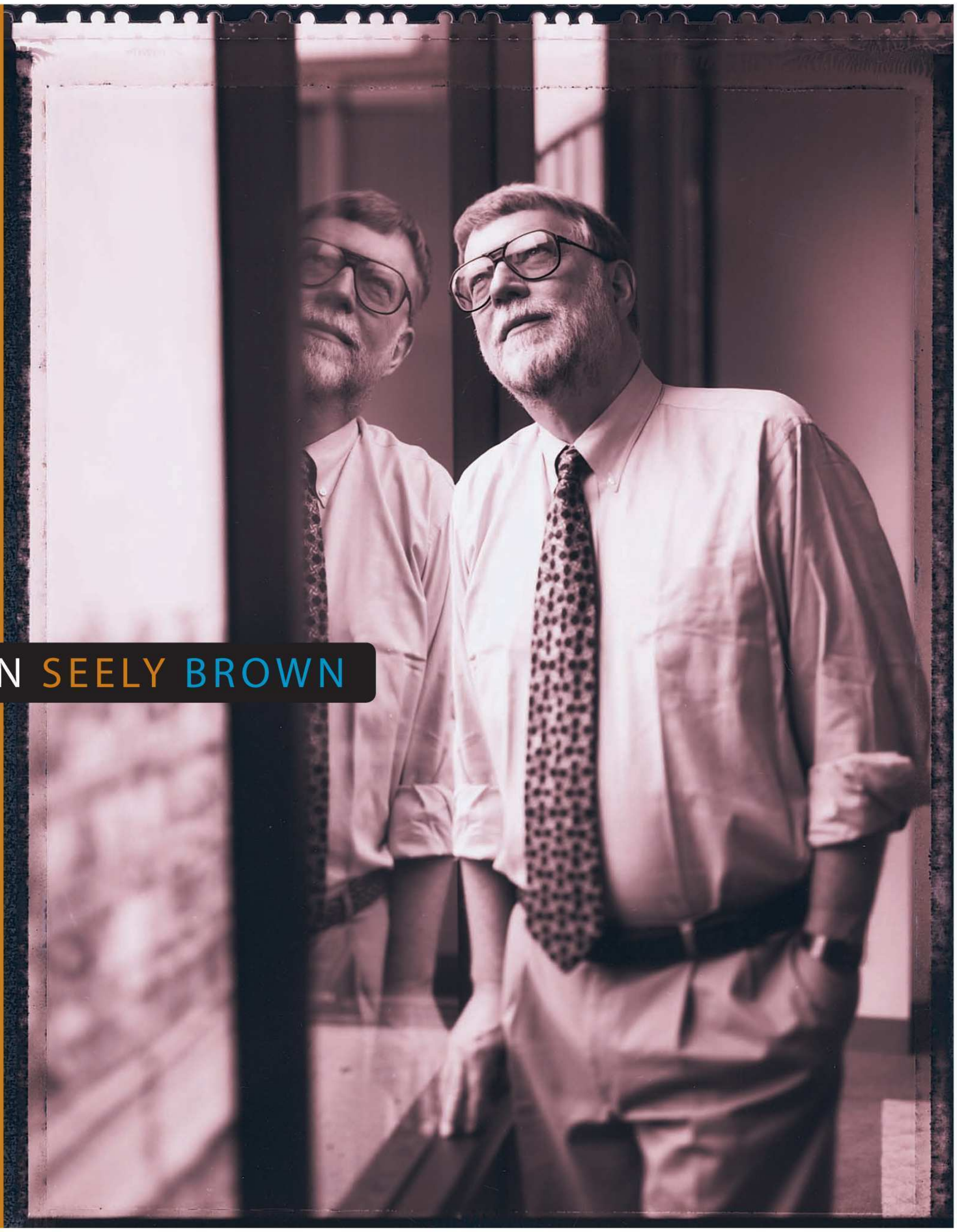
Since taking over in 1990, Brown has worked hard to avoid repeating past mistakes by shifting the lab's orientation from invention to innovation, which he defines as "invention implemented."

Computer scientist John Seely Brown came to PARC in 1978 to form its cognitive research group; in 1990 he was named the lab's director.

Today, PARC has 250 scientific and technical staff organized into five computer-based areas: Knowledge Ecologies; Smart Matter; Emerging Document Types; Networked Document Services and Devices; and Document Information Fabric. And Seely Brown, who was named Xerox's chief scientist in 1995, has emerged as a leading thinker on innovation.

"Our goal is not first and foremost to create fundamental knowledge. Our goal is to crack real problems that really make sense, but crack them by going to the root of those problems. In the process I believe very profound fundamental knowledge gets produced." A substantial part of PARC's budget is devoted to breakthrough technologies that won't appear for five, 10, or even 20 years down the road. "What PARC really does is create the genetic variance for enhancing the adaptability of the species," says Seely Brown. "The species in this case is mother Xerox."

JOHN SEELY BROWN

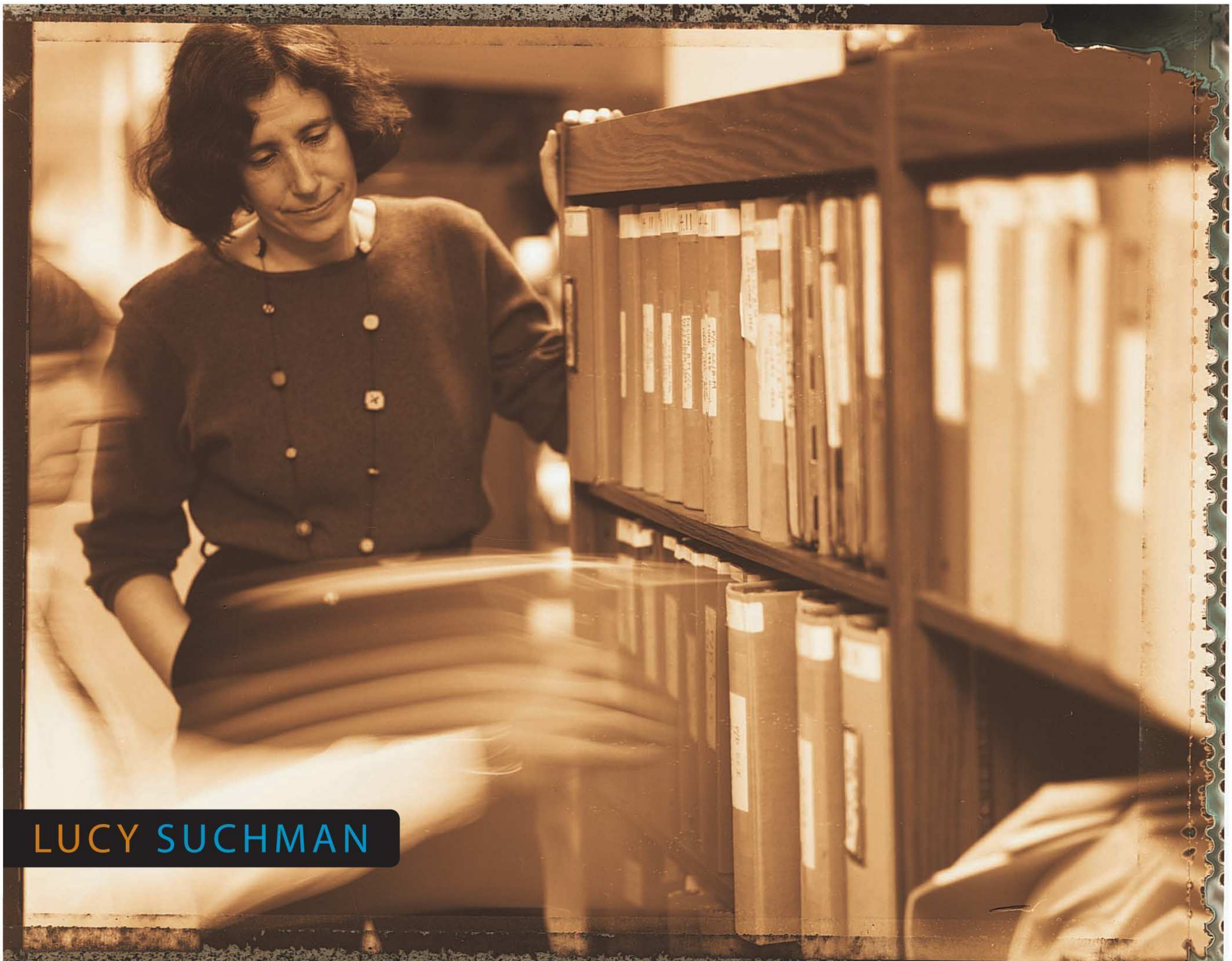


thrust was to use the power of computing—for such tasks as generating, recalling, printing, and transmitting forms—to support the way work actually gets done. At its core were technologies such as the graphical user interface pioneered at PARC. Building programs around a desktop metaphor allowed users to view items as icons or lists, either individually or as a group, providing the benefits of computerization without stripping people of control and flexibility. By adding fuel to this movement, Suchman boosted the status of her anthropology work.

But the first real milestone came about a year after her arrival when Suchman and computer scientist Austin Henderson made the two films showing researchers grappling with the 8200 copier. The machine was outfitted with powerful new capabilities such as automatic feeding and double-sided copying. But what Xerox had billed as a self-evident copier was proving a disaster in the real world. As customers complained in droves that the machine was too complicated, engineers brought the problem to PARC. Suchman and Henderson had an 8200 installed at the facility, announced their intention to set up video cameras, and asked colleagues to try it out.

Around the time John Seely Brown aired their results to various management groups, the researchers were doing the same for Xerox engineers in Rochester, New York. The more serious film (without Jane Fonda) was called "The Machine Interface from the User's Point of View." Because it featured doctorate-wielding computer scientists, it couldn't be dismissed on the grounds that people were technically incompetent—and it made a deep impression. "They were really sobered by it," relates Suchman. But rather than chastising the engineers over the 8200's shortcomings, she tried a positive tack. "The point I really tried to make was that they should not take it as evidence of their failure, but as evidence of the difficulty of the problem they as designers had to solve."

Rochester rose to the challenge. Today, instead of the 8200's flashing error codes



The doyenne of PARC's anthropologists, then Cal-Berkeley graduate student Suchman arrived at PARC in 1979 and has devoted her career to the design of more useful technologies—those that really fit what people are trying to do. Part of her philosophy is that good tools often require lots of learning, no matter how easy or intuitive they're supposed to be. "There is no such thing as a self-evident interface," she maintains.

Suchman's films of researchers struggling to use copiers sparked Xerox's wider forays into workplace studies and contributed to her influential dissertation, published by Cambridge University Press as "Plans and Situated Actions: The Problem of Human-Machine Communication."

Today, Suchman heads the Work Practice and Technology group, home to PARC's half-dozen anthropologists. Her PARC colleagues envy her ability to travel without showing any signs of jet lag.

that had to be looked up in flip cards attached to the machine, a display panel on Xerox's Series 10 and 50 copier lines shows a picture of where the trouble lies. The friendlier user interface has helped slash the average time needed to clear a paper jam from 28 minutes to under a minute. Of more fundamental importance, the films opened Xerox's eyes to the potential of workplace studies. "That was what really got us going," asserts Brown, "recognizing that it's technology in use that creates value, not technology per se."

It wasn't long before that realization brought PARC's anthropologists out of the lab to encounter machines in their natural habitat. Today, from a lone practitioner initially focused simply on observing work practices, such "ethnographic" efforts have swollen to about a dozen anthropologists, artificial intelligence experts, and computer scientists striving to create technology based on the nature of real workgroups in the real world. Their twin goals—probing fundamental aspects of work while designing technologies to make specific jobs easier—have established anthropology as at once one of PARC's farthest-out pursuits and one of its most targeted. "The idea of a corporate research center investing in anthropology may seem exotic," admits Suchman. "But in many ways we think of ourselves more as champions of the mundane. Others dream of far-out widgets. We're saying we really have to give people more useful widgets."

BRANCHING PATHS

AS PARC'S ANTHROPOLOGICAL STUDIES grew, they branched out along two main paths: workplace studies aimed at designing new office technologies and parallel attempts to strengthen internal Xerox operations such as service groups. Suchman heads the first effort, which really got going in 1989 with the study of two airline control operations, handling gate assignments, meals, luggage, and the like, at San Jose

International Airport. In the early 1990s, a second project was initiated at a Silicon Valley law firm.

While the airport project involved detailed observations of the workplace, its successor at the law firm marked an early attempt to design technology based on what the ethnographers observed. (Suchman and her colleagues call this "case-based prototyping.") The two-year effort focused on "M," an attorney whose file cabinet held records that served as templates for drafting other documents.

After pondering videotapes of cabinet-scouring lawyers in action, Suchman and colleagues Jeanette Blomberg and Randy Trigg copied, scanned, and digitized 862 documents, about a quarter of M's cabinet. Computer scientist Trigg then led a collaborative effort with other PARC researchers to design and build a prototype search aid capable of retrieving not just text but document images, which could be presented as thumbnail reproductions spread across the electronic "desktop." Although the shrunken images were illegible, searchers could find the right ones by recognizing a letterhead, or even the pattern of words on a page—much the way attorneys might leaf through a pile of papers without reading each one.

Although the search technology was improved several times in consultation with subject "M," it was never intended as anything more than a prototype. In the next field study, however, which started in 1996, the researchers were attuned to commercial possibilities from the start. The "tribe" in question this time is Caltrans (the California Department of Transportation), which is designing a replacement bridge to span the Carquinez Strait at the northeast end of San Francisco Bay.

The PARC team on this project, set to last through 1998, includes anthropologists Suchman and Blomberg, joined by computer scientists Trigg and David Levy. Their efforts focus on a contingent of about a half-dozen engineers based at the Caltrans district headquarters in Oakland, across San Francisco Bay about 45 minutes northeast of Palo Alto. To complete its work, however, the Caltrans group must interact with consultants, contractors, and public and government organizations. So the Xerox contingent has dutifully followed them through the urban jungle to a variety of meetings and made extensive visits to the towns bordering the planned construction site, another half-hour north of Oakland.

The Caltrans engineers assemble information from all these venues into project files kept in three-ringed binders. The challenge for Xerox is to move this diverse body of graphical, printed, and hand-written documents (engineering drawings, maps, surveys, letters, memos and more) from the paper world into the digital domain. To that end, PARC staffers help scan and digitize these documents, then provide technologies for indexing, accessing, and viewing the data on a web-based interface.

This digitizing may seem easy. Every office has a scanner these days, right? It's not. Scanned documents are typically converted from bit-mapped images to text, allowing users to cut, paste, and perform other word processing tasks just as if they had been created on a computer. However, the Optical Character Recognition process that makes this possible cannot handle drawings, photographs, and handwriting, and the Caltrans records are loaded with all three.

To get around this problem and give Caltrans access to all its records in digital form, the PARC team created a hybrid application called the Integrator that allows the engineers to search, retrieve, and peruse both text and image-based documents together. While the Integrator incorporates the novel thumbnail technology prototyped in M's records, what really makes it unique is the ability to search for images based on features such as signatures or letterheads. Suppose, for example, that an engineer needed to know the names of everyone with whom she had corresponded in a given month. The Integrator could retrieve all the letters bearing her signature and also provide a summary that listed all the addressees. With a click of the mouse, the engineer could call up and print any of those letters, or send them over the web to a colleague. In late 1997, the PARC team filed patents on the image-based search and summarization features.

For Xerox, beyond helping a major customer (the state of California) maintain

The challenge for Xerox is to move a diverse body of graphical, printed, and hand-written documents—engineering drawings, maps, surveys, and more—from the paper world into the digital domain.

Tubular hell. These Caltrans blueprints stump current scanning systems.

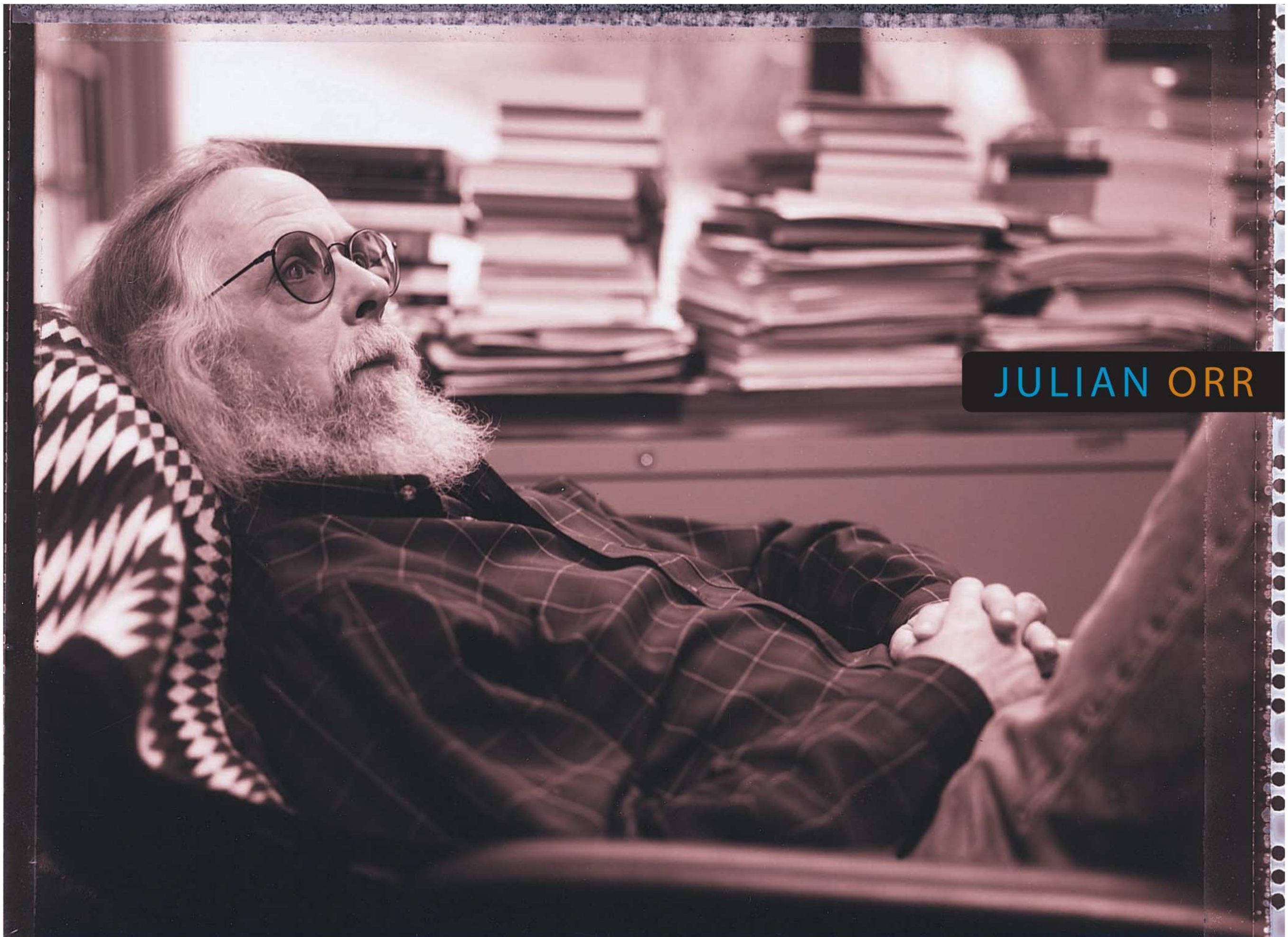
records, the Caltrans arrangement provides a real-life test bed for a technology aimed at a variety of products. The workplace study is done in close collaboration with Xerox's Office Document Products Group, which hopes to use technologies like the Integrator in its Document Center Systems line of networked multifunction machines that copy, scan, store, print, and fax all from the same box. Such a strategy marks almost a reversal of normal product development. Typically, notes Suchman, developers start with a general technology and customize it for individual customers. In the Caltrans case, researchers began with a detailed study of a particular job, developed specific tools for helping engineers, and then worked backward to create a powerful general technology applicable to many domains.

TURNING INWARD

A SECOND THRUST OF WORKPLACE pursuits—focused on internal Xerox operations—can be traced largely to Julian Orr, a bearded, motorcycle-riding PARC technician-turned-anthropologist. As Suchman had in her study of office clerks, Orr observed that service people rely on knowledge obtained outside training sessions or manuals. For instance, individual copiers have various idiosyncrasies, giving rise to problems that must be divined through on-the-spot diagnosis and relayed through informal storytelling sessions over lunch or at the parts drop.

In 1992, Orr initiated a Denver-based field test that gave Xerox technicians two-way radios so they could share tips and insights without having to share lunch; all U.S. service reps now have radios or cell phones. His work also helped inspire Eureka, an effort between PARC's Smart Service team and a Xerox unit in France that allowed technicians to distribute choice tidbits not by radio, but via a digital "watering hole" accessible through the country's ubiquitous Minitel electronic telephone directory system.

Led by PARC computer scientist Olivier Raiman, Eureka took off in 1995 with a large-scale field effort. The Minitel-linked central database was created to hold servicing tips arranged by category and machine. Any technician wishing to contribute a new



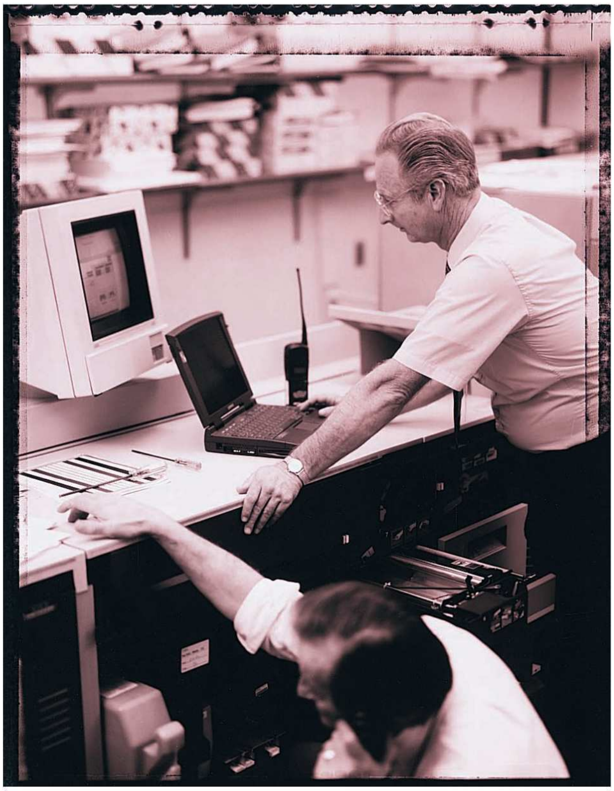
JULIAN ORR

In the years between graduating high school in Afghanistan (where his father worked on a U.S. foreign aid contract) and completing his doctorate in anthropology from Cornell, Orr served as an Army encryption equipment technician, gas station night manager, and PARC computer and printer serviceman. He made good use of his experiences: His dissertation-turned-book, *Talking about Machines,* was based on observations of Xerox copier service personnel.

Orr became a full-fledged researcher in 1984. A key asset anthropologists bring to a place like PARC, he believes, "is the ability to go out and see what people are doing without a lot of preconception." Orr raises Navajo sheep and Hanoverian horses and keeps a small stable of BMW motorcycles. To take his mind off difficult intellectual problems, he likes to take one of his motorcycles and go for a long drive through the Santa Cruz mountains.

item first sent his suggestion to a team of validators who made sure the idea was valuable. Approved submissions were then placed in a New Tips category, along with the originator's name. The study showed a 5 to 10 percent savings in parts and labor, catapulting the French service force into one of Xerox's best. Between 1995 and the end of 1997, about 20 percent of French technicians had submitted a validated tip. Eureka was consulted 7,000 times a month, an average of almost six times for each French service rep. The electronic hotsheet proved so successful that early in 1997 it was extended to 1,500 technical Xerox reps in Canada. Now, in mid-1998, a similar rollout is reaching the 12,000-strong U.S. service force.

Even as Eureka goes global, PARC is preparing an offshoot called Alliance aimed at bringing Xerox service reps together with salespeople. Technicians often know when customers are ready to purchase new copiers. Yet because of differences in the way sales and service territories are assigned, even if one wanted to



Service calls. Xerox repairmen.

In 1992, Orr initiated a Denver-based field test that gave Xerox technicians two-way radios so they could share tips and insights without having to share lunch; all U.S. service reps now have radios or cell phones.

alert a salesperson to a hot prospect, it would be difficult to find the representative handling a particular account. Much like Eureka, Alliance uses e-mail and central databases to make the connection. Tipsters also garner a modest finder's fee such as a dinner for two. Not long after its fall 1997 launching, the program was claiming more than a million dollars in deals generated each month directly from service people in France alone. Says PARC research fellow Daniel G. Bobrow, who heads the Scientific & Engineering Reasoning Area that developed Eureka and Alliance: "It's easy enough to use that a service person can send a message and the salesperson can be calling the customer while the service person is still there."

Because the introduction of technology often spawns new problems, all these efforts are fraught with perils that provide grist for the mill of anthropology. In Eureka's case, for example, the absence of a Minitel-like system in Canada and the United States has dictated a complete technical revision and generated a host of logistical and budgetary headaches. Bobrow reports that while it's relatively easy to get top people to sign on, effecting changes gets harder as responsibility for implementation is delegated down, since each stop along the way disrupts somebody's budget. Even if managers spring for laptops, there remain the questions of how workers will accept and utilize computer-based tools—with the answers feeding back in to the design of additional tools.

THE UNIQUENESS OF PARC

John Seely Brown emphasizes that PARC's anthropology work highlights how far the facility has come, especially in regard to the constant interaction with Xerox colleagues and customers necessary to encourage successful innovation. In the old days, explains the director, a PARC denizen since 1978, "We were these elite scientists sitting in this building inventing the future. Already, talking about 'inventing the future' smacks exactly of the ontological problem. We don't invent the future. We can help enact the future—but we must work with others in making that happen." Brown cites the anthropological efforts as an example of pioneering research, because they start with real business problems and then reframe the issues to devise never-before-considered solutions—and it is through just such a tactic that he expects PARC's biggest payoffs. "Our goal is not first and foremost to create fundamental knowledge," he relates. "Our goal is to crack real problems that really make sense, but crack them by going to the root of those problems. In the process I believe very profound fundamental knowledge gets produced."

For Lucy Suchman, the mix of real-world problems and more academic investigations into the nature of work is particularly attractive. "One of the good things about working at a place like PARC is that you can do both those things," she maintains. "I do think that PARC is quite unique in its continued commitment to having near-term problem solving and long-term research both be part of what the place is about."

Even after nearly two decades spent studying how people in organizations learn and interact, Suchman is fascinated by the way once-isolated researchers are having their eyes opened as the walls between "R" and "D" come down—some of it because of her own efforts. Asserts PARC's original anthropologist, "They discover that the people in other parts of Xerox are extremely interesting and intelligent."

"And that," she adds, "is when good things really happen."

The Next Genome Project

Biotech's gene hunters are turning their efforts to the world of proteins. It's a vast and uncharted territory, so they're going to need a *really* big map.

By Antonio Regalado

Stacks of clues: Myriad Genetics prepares yeast colonies to map networks of protein interactions.

COURTESY OF MYRIAD GENETICS

BACKGROUND COURTESY OF NATURE GENETICS, P. LEGRAIN

The human genome project—molecular biology's international extravaganza that seeks to decode all of humankind's estimated 100,000 genes—is on track to be completed in 2005. Researchers know that each of those genes contains a precise molecular script for making a different protein. But after spending several billion dollars on the Genome Project over a decade and a half, scientists will simply have gathered the cast of characters for another fundamental mystery: What in the heck do all these proteins do?

On biology's stage, proteins are the leading players—as well as the producers and directors. Acting alone and in groups, proteins do just about everything in a cell, from shuttling urgent messages to controlling the cycle of growth and death. It's the role of proteins that scientists need to know to unravel the secrets of life—and to develop potent new drugs. In fact, in one sense the Human Genome Project and its counterparts for other organisms, such as flies, worms, viruses, and bacteria, are simply precursors of a great Human Protein Project. Yet the efforts to decode the genes of less complex creatures are bringing advance notice of just how poorly lit the world of proteins really is.

Take baker's yeast. A staple of genetics labs, researchers finished sequencing its genome—all 6,000 genes—in 1996. Each of the strings of genetic "letters" predicts the basic makeup of a protein. "But we still have no idea whatsoever what nearly half of those proteins do," laments Roger Brent, a geneticist at the Molecular Sciences Institute in Berkeley, Calif. "And yeast is one of the most intensively studied organisms."

Today's research techniques are woefully inadequate for

explaining the function of so many proteins. Typically researchers will breed "knock-out" mice missing a particular gene, then study what effect the loss of the corresponding protein has on the animal—an approach that is like trying to understand how a carburetor works by removing it and checking to see whether the car still runs. Thanks to the rapidly growing availability of the DNA sequences of genes, scientists are gaining a neatly labeled inventory of parts. "What we need now are fast ways to find where and how all those parts fit," says Brent. "We need to apply high-throughput approaches to studying proteins."

The field developing these approaches is called "protein genomics," or, more catchily, "proteomics," and it's one of the hottest areas of biotech. Over the past year, research in this sector has spawned an array of high-tech startups, including Genome Pharmaceuticals, a spin-out from Germany's Max-Planck Institute, and Hybrigenics, a Paris-based venture. Established gene-hunting firms are also moving aggressively into proteomics. Cambridge, Mass.-based Millennium Pharmaceuticals, Genome Therapeutics, and Incyte Pharmaceuticals of Palo Alto, Calif. all have research groups. These genomics companies bring to the protein game qualities honed over half a decade of searching for genes: a taste for big projects and an aptitude for automated, high-speed science.

The biggest and most advanced of today's proteomics efforts aim at revealing how proteins interact with one another. It's by acting in complex networks that proteins command critical processes such as the way cells translate outside signals into biological "to-do" lists. Like a game of molecular telephone, signals are passed along chains of interacting proteins. To find out what happens in cancer—or in health—researchers need to find out just which proteins are working together.

At the Salt Lake City headquarters of Myriad Genetics, a row of 14 research robots has been whirring away since last November on this problem. The robots are part of an ambitious effort to construct what's known as a "protein interaction map," says project director Arnold Oliphant. "We're taking every protein encoded by the human genome and asking which other proteins it binds to." Interaction mapping is only one of several proteomic technologies, but Myriad is betting it is the fastest way to determine the function of a large number of proteins. Finding that a protein of unknown function can bind to one whose cellular task is known, says Oliphant, "is like finding that a particular screw belongs in the carburetor. You get a pretty good lead on what it's for."

But, with an estimated 100,000 proteins produced in the human body, there are a daunting 50 billion possible protein-protein combinations to test. Myriad figures there are probably half a million actual interactions to discover. "It's a big undertaking," Oliphant says, "but we think this information is going to be phenomenally valuable."

The big payoff could come in finding new drug targets. Until recently, genomics firms like Myriad were mostly in the business of tracking down disease genes by studying inheritance patterns. That's how Myriad helped uncover a gene called BRCA1 that has been linked to breast cancer. But just what the gene's protein does in the body is unclear. As a result, it's not a decent drug target. That's where the interaction map could prove handy—by helping to delineate just what the protein product of BRCA1 does and what other proteins it interacts with.

There are already some clues. Oliphant says Myriad scientists have discovered that

Protein Interaction Mapping Projects: Academia

Investigator	School	Location	Organism
George Church	Harvard	Cambridge, Mass.	E. coli * (bacterium)
Stanley Fields	University of Washington	Seattle	S.cerevisiae (yeast)
Russell Finley	Wayne State	Detroit	Drosophila (fruit fly)
Pierre Legrain	Pasteur Institute	Paris	S.cerevisiae (yeast)
Marc Vidal	Mass. General Hospital	Boston	C. elegans *(nematode)

*Experiments not yet under way

Sex and Death among the Yeasts

Sex, death, and a robot. Geneticist Stanley Fields' work has all the makings of a science-fiction best seller. The only catch: The protagonist is baker's yeast.

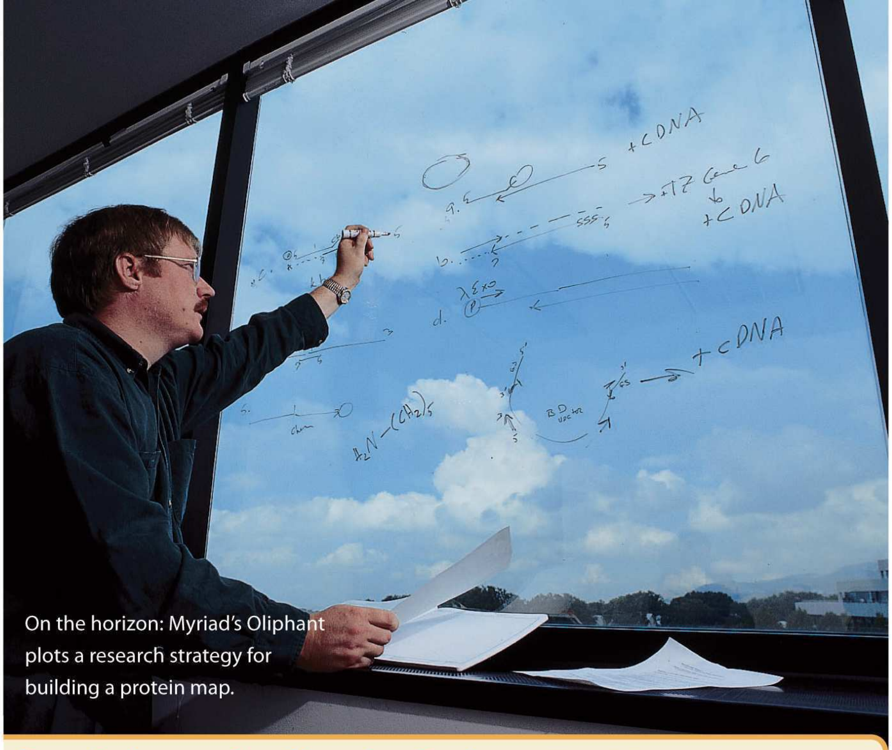
Fields is assembling 12,000 yeast colonies in his University of Washington lab to create an "interaction map" that will chart which of the much-studied fungus's proteins bind to each other (and which ones don't). Other groups are drawing similar maps for their own favorite organisms, and biotech companies are doing the same for human proteins. All these mapping efforts are aimed at understanding the function of proteins, and nearly all apply high-speed versions of an innovative recipe (called the two-hybrid system) that Fields developed in 1989.

The main ingredients are transcription factors (proteins that have a key role in gene expression, the process by which DNA is used to make proteins). The first step: Break the gene for a vital transcription factor in two. Then, fuse genes for test proteins (from yeast, or from any other organism) into each half. Package it all back into a single yeast cell. Only if the two test proteins interact, Fields explains, will halves of the transcription factor connect so that the factor can do its job. If it does, the yeast lives; if it doesn't, the yeast dies.

The technique is now widely used to see whether any given pair of proteins can bind to each other. But in its existing version the technique is too slow to take on all 6,000 yeast proteins, which can form 18 million possible protein-protein combinations. "So we've spent the last two years trying to scale it up," says Fields. That's where robotics and sex come in. Fields' team has prepared 6,000 yeast colonies, each containing a different yeast gene fused to half a transcription factor. These are the "fish." He's also preparing 6,000 "bait"—each a yeast colony with one of the same 6,000 genes linked to the transcription factor's other half.

Fields spreads a lawn of one of the bait onto a sheet of plastic; then a research robot systematically dabs spots of all of the different fish on top. Bait and fish mate, merging their genetic material. By looking to see which spots grow and which die out, Fields' group knows which pairs of proteins interacted. "We'll be repeating that experiment 6,000 times, each time with a new [bait]," explains Fields.

His team aims to complete the survey in about two years, generating a detailed road map connecting each yeast protein to all its possible partners. The map, Fields expects, will guide scientists touring the organism's basic biology and pave the way to new discoveries.



On the horizon: Myriad's Oliphant plots a research strategy for building a protein map.

COURTESY OF MYRIAD GENETICS, INC.

Protein Interaction Mapping Projects: The Private Sector

Company (year founded, status)	Location	Organism
AxCell Biosciences (1997, private)	Princeton, New Jersey	Human
CuraGen (1993, private)	New Haven	Human, mouse, rat
Functional Genomics Systems (1997, private)	Berkeley, Calif.	Human
Genome Pharmaceuticals (1997, private)	Munich	Human*
Genome Therapeutics (1991, public)	Waltham, Mass.	Human*
Hybrigenics (1997, private)	Paris	Human, HIV, hepatitis C, *H.pylori*
MorphoSys (1992, private)	Munich	Human*, pathogens
Myriad Genetics (1991, public)	Salt Lake City	Human

*Working on selected protein networks only

BRCA1's protein binds to another protein, known as CtIP, which has been identified as a bit player in an important cancer pathway. By connecting the dots, Oliphant hopes to better understand BRCA1's role and find the Achilles' heel that could be the first step in developing a drug to prevent at least some types of breast cancer.

Not everyone is convinced that such protein interaction maps will pay off. "Everyone's searching for the next big technology. But I'm not sure we're there yet," says Jean-François Formela, a venture capitalist at Boston's Atlas Venture. "It's too random, too much of a long shot," says Formela, who thinks the money could be better spent on more directed research rather than the brute-force effort to find all possible protein-protein interactions.

And, to be fair to the skeptics, large-scale interaction mapping efforts face two key obstacles. The first is that not all human genes are known. This doesn't actually stop researchers from recording protein interactions, but it does require them to jump through some genetic hoops. The result, say critics, is data that are potentially "noisy." Furthermore, nearly half of the interactions detected by most mapping efforts can later turn out to be biologically irrelevant.

At the New Haven, Conn., laboratories of genomics firm CuraGen, researchers building a protein interaction map have instituted a series of controls for filtering out the noise. But CEO Jonathan Rothberg, who's been mulling the protein interaction problem over for a decade, says that even after the filtering, "every one of those interactions needs to be confirmed." As opposed to the rapid-fire genetic voodoo used in the first pass (*see sidebar on page 52*), these follow-up tests apply standard, relatively slow methods. But because the number of detected interactions is fairly small, Rothberg says this task is "definitely doable."

Oliphant agrees that one way or another the interaction map is going to be the fastest, cheapest way to link proteins to their function on a large scale. Indeed, Oliphant ambitiously predicts Myriad will complete the entire human interaction map in less than five years. His team is beginning with 8,000 well-characterized human genes from public gene banks and the company's own collection. They'll use the proteins coded for by these genes as bait to fish for interactions in a genomic pool stocked with a complete collection of human gene products. For each initial piece of "bait," Oliphant expects to fish out two to five interacting proteins. Some will be familiar, others will be entirely new. "We'll characterize the novel ones, then use them as bait for the next fishing expedition," he says.

While scientists at CuraGen and Myriad labor to unravel the protein interactions in humans, others are also looking to help create new drugs by taking on other organisms. Hybrigenics, which was founded at the end of 1997 to exploit interaction mapping strategies developed by French researchers including molecular geneticist Pierre Legrain of the Pasteur Institute, plans to create maps of pathogens such as HIV, the hepatitis C virus, and the ulcer-causing bacterium *H. pylori*. "A map of HIV will help define alternative drug targets," says Hybrigenics' founder, A. Donny Strosberg. That could prove critical because of the deadly virus's growing resistance to today's drugs.

Academic researchers are also laying plans to chart the proteins of their favorite research organisms—including yeast, the bacterium *E. coli*, and the fruit fly, *Drosophila*. But it's likely that most of the action will continue to play out at biotech companies because the Human Genome Project will be grabbing the lion's share of federal funds for big science in biology for years to come. "There's no international proteome project yet," says Marc Vidal, an investigator at Massachusetts General Hospital who is trying to cobble together enough grants to start building an interaction map of the worm *C. elegans*. "But we talk about it over beer."

Molecular Sciences' Brent is not waiting idly. He's beating the pavement to raise $1 million to fund a startup company called Functional Genomics Systems, which he says will undertake to map human proteins. But after selling drug companies first crack at the data, Brent says he will make it available to the public. "The technology is in place," he says. "Now it's just a matter of shoveling and money."

The ribbon has been cut and the foundation is being laid. The great human protein project is underway, a biomedical monument for which the Human Genome Project is but the blueprint.

Companies That Listen to Their INNER VOICES

In an exclusive excerpt from his new book, *The Productive Edge*, MIT's Richard Lester argues for a "New Economic Citizenship"—based partly on the strategies of America's winning companies.

By Richard K. Lester

Last year the Levi Strauss Corporation announced the closure of 11 U.S. factories. Six thousand employees—one-third of its North American workforce—would lose their jobs. Just another downsizing American corporation, prowling the globe for low-cost labor to replace its unwanted domestic workers? Hardly. In what *The New York Times* called "an extraordinary gesture of largesse," Levi's softened the bad news for its employees by providing remarkable severance benefits. All the laid-off workers, the company said, would be given eight months' notice, three weeks of pay for every year worked, and $6,000 in benefits to cope with the dislocations of job loss. And unlike the case with most severance packages, the workers could collect even if they found a new job the next day. In addition, the company announced that it was making gifts totaling $8 million over three years to the communities affected most severely by the retrenchment. Even union officials praised the company's handling of the layoffs: "By far the best severance settlement apparel workers have ever gotten," said one.

DOUG KNUTSON

While Levi's gesture was extraordinary, it wasn't a departure for the company. Treating its employees fairly and valuing their contributions have long been hallmarks of the way Levi's does business, and the company is well known for offering its employees opportunities for growth and for sharing with them the wealth created by its successes. These core values are also reflected in the company's principal business strategy since the 1980s—upgrading what had been a very basic, inexpensive commodity, blue jeans, into a range of high-priced fashion products. When coupled with investments in new technology and with new manufacturing methods, this strategy has enabled Levi's to retain many of its domestic manufacturing jobs long after most other apparel-makers outsourced their operations to low-wage countries.

Levi's powerful commitment to its employees' welfare has served the company well, helping it to post 10 consecutive years of record sales between 1986 and 1996—almost tripling revenues during this period. And Levi's is not alone in either the strength of its values or their consequences. The research done for my new book, *The Productive Edge,* from which this article was adapted, suggests that an enduring, deep-rooted commitment to a handful of core beliefs about corporate identity and purpose helps to explain the accomplishments of other durably successful companies too. The specific content of those beliefs varies from firm to firm, but in each case they are understood by everyone in the company and infuse almost every action it takes. They have guided and inspired successive generations of employees. In effect, they are the glue that has held these companies together and enabled them to grow over long periods.

DOUG MENUEZ/SABA

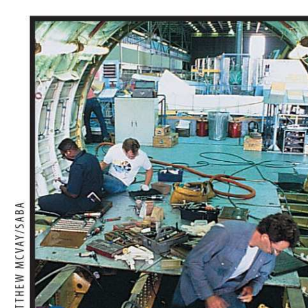
Ultimately, even Levi's couldn't completely insulate its employees from the effects of cutthroat global competition and technological change (and, in this case, the fickleness of fashion). Though the Levi's workers helped the company create new economic value—in which they themselves shared—their future roles couldn't be ensured. The events at Levi's bring into especially sharp relief the forces now sweeping the whole U.S. economy as it confronts the historic challenges of global integration and the digital revolution. Each presents tremendous opportunities for economic growth. But for the American workforce each also means more volatility and a loss of control.

JAMES SCHNEPF/GAMMA LIAISON

Losing the Productive Edge

With the U.S. economy still humming in the eighth year of this century's longest expansion, the nation's political and business leaders are in a self-congratulatory mood. There is indeed much to celebrate: strong job growth; unemployment and inflation at their lowest levels in decades; a soaring stock market; consumer confidence at record levels; American firms dominating world high-technology markets. Small wonder then that the issue of "economic insecurity," once expected to dominate the politics of the 1990s, has faded into the background.

But the ultimate test of any nation's economic performance is the prosperity of its citizens, and here the news isn't quite so good. True, many Americans (especially the more affluent ones) have seen their incomes go up recently. But nearly half of all American families still have incomes below $35,000 per year—less than what most people regard as being necessary to live in reasonable comfort. Moreover, the economic circumstances of the majority of families haven't improved much in two decades. Indeed,



MATTHEW MCVAY/SABA

by one estimate the incomes of the least affluent 60 percent of families are lower now than they were in 1979, after adjusting for inflation.

In the long run, no country can enjoy sustained growth in its standard of living unless it also achieves a healthy rate of productivity growth, and the single most important factor behind the disappointing statistics on U.S. living standards is the weak productivity growth of the American economy.

During the 100 years leading up to the early 1970s, America's productivity, expressed in terms of output produced per hour of labor, grew at an average rate of about 2.3 percent per year. The result was a twelvefold increase in productivity over this period, and a dramatic increase in American living standards. Sometime in the early 1970s, however, the rate of productivity growth declined sharply, and for more than two decades the U.S. economy has been stuck in low gear. Labor productivity during this period grew at a rate of about 1.1 percent per year. A decline from 2.3 percent to 1.1 percent might not seem very significant, but over a long period it matters a great deal. If productivity growth in the past 25 years had matched the previous century's average growth rate, American household incomes would be about 35 percent higher than they are today, and millions more American families would be enjoying a middle-class standard of living.

What must we do to regain the productive edge? There is no one simple answer to this question. But a key part of any solution is more investment. Today the combined forces of globalization, technological innovation, and the deregulation of many industries at home and entire economies abroad are creating enormous opportunities for American firms to invest in the development of new products, services, and markets. Yet the very forces creating such great potential for growth are simultaneously giving rise to unusually turbulent business conditions. What actions and strategies are most likely to produce a higher rate of productive investment in this environment?

Today some of America's greatest economic assets are its nurseries of innovation—its deep, sophisticated venture-capital markets; its system of industrially connected, high-quality research universities; and an entrepreneurial culture that encourages risk-takers and rewards them handsomely when they succeed.

But after studying the origins of America's industrial revival over the past decade, I have concluded that a group of successful mature companies—Levi Strauss among them—also have important lessons to teach us about growth under conditions of uncertainty. These firms are all quite different, but they all share one fundamental quality: a powerful, lasting awareness of identity and of values extending beyond the bottom line. Over the years these companies have exhibited a sense of *purpose beyond profit* that, paradoxically, has helped them to increase their profitability, and to navigate through periods of great uncertainty along the way. There are important lessons here for other companies. And, as we shall see, for our society as a whole.

Winners and Losers

IN ONE SENSE, THE PRODUCTIVE EDGE IS A SEQUEL TO MADE IN *America,* a book that summarized the conclusions of MIT's Commission on Industrial Productivity on the overall performance of the U.S. economy in the late 1980s. The commission (of which I was a member) analyzed firms in eight sectors of the economy and identified striking similarities in what the most successful firms in those industries were doing. Most features of what we called "best practices" (such as breaking down internal organizational barriers, flattening hierarchies, developing closer links with customers and suppliers, adopting innovative human resource practices, committing to continuous improvement, integrating new technology with production and marketing strategies) were relatively well known even then, and have since become conventional wisdom. But what was most striking about the leading firms was their ability to see these practices not as independent solutions but rather as part of a coherent system. While most companies had settled for piecemeal reform, the most successful firms recognized the need for systemic change and the importance of aligning their organizational practices with one another.

But that begged another, deeper question: Why? Why had *those* firms and not others understood the need for dealing with change as a whole, not as a set of separable tactics to be selected as if from a menu? To answer that question, my colleagues at the MIT Industrial Performance Center and I more recently went back to many of those same companies.

As we went from one firm to another, we got a surprise. We had expected that market pressures would be the strongest impetus to transformation. But the top managers we interviewed frequently pointed to another source. Even though the market is never absent from the manager's mental screen, market perturbations seemed to be playing a less direct role than we had imagined. More often, the driving force for change seemed to be coming from within.

Inner Voices

THE INJUNCTION TO "LISTEN TO THE VOICE OF THE CUSTOMER" IS today one of the most common forms of advice to business. Indeed, for many firms it has attained almost religious significance. Yet as we revisited the firms in our group, we could not help noticing that, while listening very carefully to what their customers were saying, the employees—at every level—also seemed to have an understanding of their mission that transcended the customer's voice. It was

ANN STATES/SABA

Treating its employees fairly and valuing their contributions have long been hallmarks of the way Levi's does business, and the company is well known for offering its employees opportunities for growth and for sharing with them the wealth created by its successes.

Levi's manufacturing plant in Blue Ridge, Georgia

as if they were also listening to an *inner* voice, a voice that was not always in perfect harmony with the voice of the customer. As William Weisz, former CEO of Motorola, once put it: "When you are pioneering in something the world doesn't even know it wants, you have to have a belief that the world is going to want what you have, and that it will start falling all over its feet to get it."

Similarly, though these firms were paying very close attention to their competitors, their actions in the marketplace were not purely reactive. Their strategies were shaped as much by a core belief in what they were trying to accomplish as by the drive to pre-empt or mimic the competition. These are companies that never seem to stop thinking hard about who they are.

Take Boeing, a firm with a history of taking huge financial risks—"betting the company" to build the next generation of planes. The best-known example is the 747. One of the greatest gambles in aviation history, the development of the hugely expensive 747, like other Boeing projects before and after, was not really a response to a competitor, since no other company was then seriously entertaining such a project. Nor was the project justified purely on the basis of return on investment. Indeed, given the risks involved for the company's existence, it is quite unlikely that such a decision could ever have been justified on purely financial grounds. Although

profitability was always involved in the decision, by most accounts it was Boeing's sense of itself as a company whose mission is to push the envelope of commercial aviation—a company that "eats, breathes, and sleeps" aeronautics—that made the difference.

Levi Strauss, mentioned at the beginning of this article, provides a very different example. One of the few unequivocal success stories in the struggling American apparel industry over the past decade, Levi Strauss's emphasis on the long term, on building its organizational capabilities, and on increasing the contribution made by its workers to the business, has set it apart from the volatile, highly reactive, often exploitative norm in the rest of the industry.

Perhaps the biggest test of the company's commitment to these values has been posed by its network of overseas subcontractors, some 600 of them sewing Levi's in 35 countries. Though the company still relies primarily on its U.S. workforce to manufacture products sold in North America, its global competitiveness is heavily dependent on its access to the low-cost labor in many of these countries. But not all of them are known for respecting the rights of their citizens to work in safe conditions, and some have failed to meet international norms regarding human rights.

The company's top managers had to face the question of how to apply their ethical standards in such cases. The choices weren't easy. To insist on a universal standard of behavior among suppliers would rule out production (and probably also sales) in some of these countries—with immediate negative bottom-line impact. Furthermore, the loss of jobs would almost certainly be a severe blow to the employees of the affected subcontractors, for whom risky work might well be better than no work at all. On the other hand, for Levi Strauss to waive its ethical standards in its overseas dealings would smack of hypocrisy and risk alienating U.S. workers already fearful of losing their jobs to cheap foreign labor. Besides, rumors of child and prison labor don't help sell jeans.

In 1992, the company introduced new guidelines governing its dealings with overseas business partners. The guidelines asserted that the company had "a heritage of conducting business in a manner that reflects its values. As we expand our sourcing base to more diverse cultures and countries, we must take special care in selecting business partners and countries whose practices are not incompatible with our values. Otherwise, our sourcing decisions have the potential of undermining this heritage, damaging the image of our brands, and threatening our commercial success."

When we reconnected with Levi's soon after that policy was promulgated, the company was struggling to decide what to do about its operations in China, a decision that involved balancing the Chinese government's human rights violations against the costs of losing access to the potentially enormous Chinese market. Eventually, Levi's decided to discontinue all production, sourcing, and sales in China, a decision that a top executive described to us as one of the toughest the corporation has ever had to make.

Once again, the point is not that Levi's decision was driven purely by ethical, altruistic concerns. The company was clearly also very apprehensive about the risk to its brand image posed by Chinese labor and human rights policies. The point is that the decision to terminate Chinese operations grew out of a deeply held sense of what Levi's stands for, in which issues of commercial brand, corporate values, and self-image are all intertwined. It is a decision that would not—indeed, *could* not—have been made if the company had been reacting only to external market pressures.

Another example of this internally driven behavior is offered by Motorola. The successes of Motorola over the years in a wide range of communications and electronics markets cannot be ascribed purely, or even primarily, to a goal of beating the competition, even though that has very often been the outcome. But unlike Levi Strauss, what drives Motorola is not primarily a set of ethical concerns or an egalitarian philosophy. The most important motivation seems to be the more technical objective of always trying to do better than before, the impossible quest for "perfection before the customer." Mobilizing the entire company around apparently impossible goals has long been a central part of Motorola's leadership strategy. Targets such as the famous "Six Sigma" quality goal of reducing the error rate in every one of the company's processes to fewer than 3.4 mistakes per million operations have helped create a common vocabulary and sense of purpose for a company that is considerably more decentralized than most others its size. Even more important, stirring the pot this way has kept the organization moving and searching. As longtime chairman Bob Galvin put it: "It doesn't really matter what the goal is exactly. As long as it is reasonable. The point is to stimulate. To catalyze."

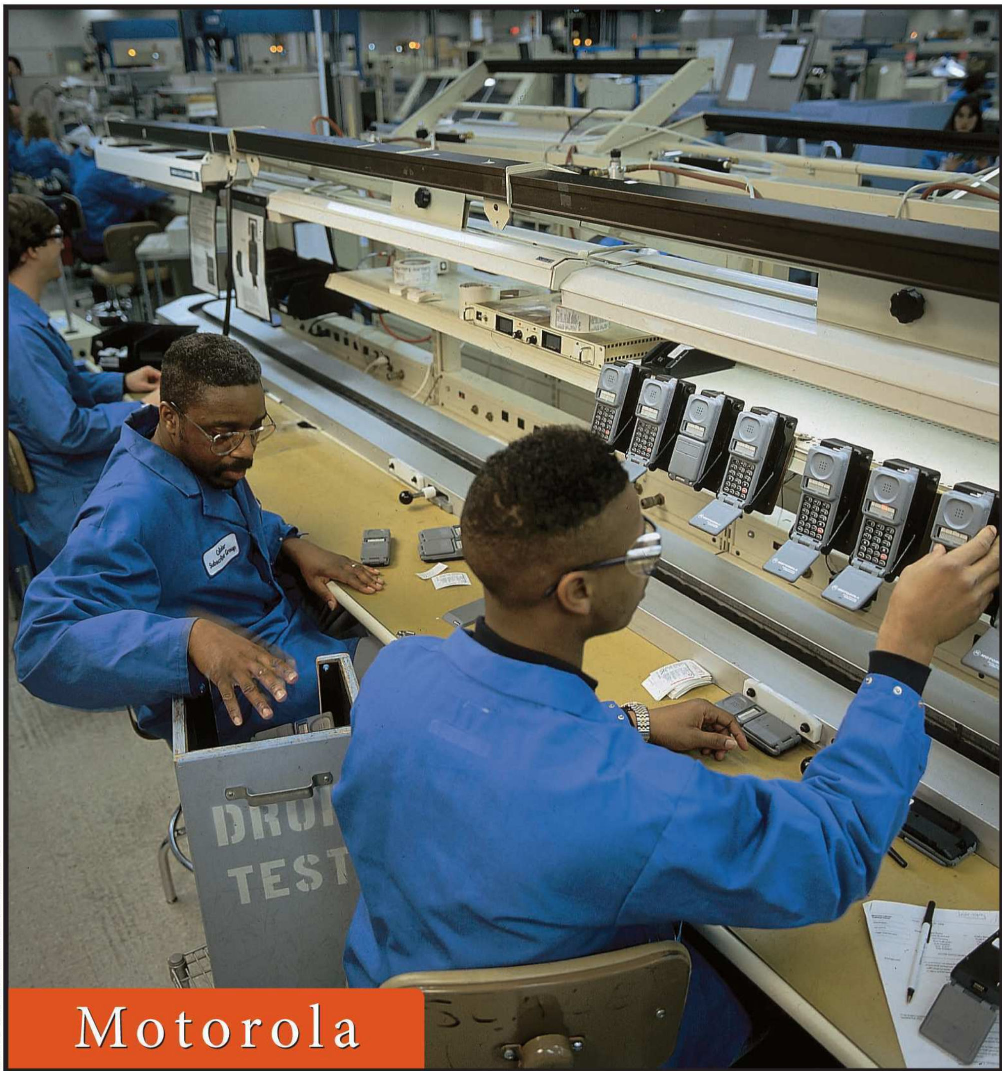
Over the years these companies have exhibited a sense of *purpose beyond profit* that, paradoxically, has helped them to increase their profitability, and to navigate through periods of great uncertainty along the way.

Galvin, who chooses his words carefully, is perfectly aware that goals such as Six Sigma quality strike many observers as less than reasonable (and the company, despite making vast improvements, did in fact fall short of the Six Sigma goal). But the idea of Motorola as a company that is driven by a long-term vision to pursue the seemingly impossible is integral to its sense of corporate self. Galvin adds: "At times we must engage in an act of faith that key things are doable that are not provable."

In recent months Motorola has been sharply criticized on Wall Street and in the business press for overextending itself, falling behind with new product introductions, and other transgressions. But Motorola has weathered worse crises in the past, and though a recovery isn't ensured this time, it would be unwise to write off an organization that over the decades has repeatedly drawn on its fundamental values to renew itself and its products.

Confirmation

THE RESEARCH THAT I AND MY COLLEAGUES HAVE CARRIED OUT over the years has convinced me that internal values are a key part of corporate success. But I can hear some skeptical readers saying "Show me." To those schooled in hard-nosed quantitative analyses of competitive situations and strategies, explanations such as this



JAMES SCHNEPF/GAMMA LIAISON

What drives Motorola is not primarily a set of ethical concerns or an egalitarian philosophy. The most important motivation seems to be the more technical objective of always trying to do better than before, the impossible quest for "perfection before the customer."

Motorola cell-phone assembly in Schaumburg, Illinois

will no doubt seem very "soft." And a handful of examples certainly does not prove that every company with a strong sense of identity and internal values is successful or that every successful company has succeeded *because* of its values.

However, further evidence to support these conclusions comes from a detailed study of 18 companies with a record of exceptional achievement extending back over many decades (several had also been the subject of the MIT research, including Hewlett-Packard, Boeing, Motorola, and Ford). In this pioneering study, conducted by James Collins and Jerry Porras of Stanford, each of the 18 "visionary" companies was carefully compared with another company of comparable vintage that had started out pursuing similar products and markets. The firms in the comparison group were themselves no slouches, and in many respects had been above-average performers. Yet each had been outdistanced by its more visionary counterpart. Collins and Porras (who published their results in a book called *Built to Last: Successful Habits of Visionary Companies*) asked what had distinguished the most successful companies from their competitors.

Their answers undermine many of the most pervasive myths about effective corporate management—for example, that business success requires a single-minded focus on maximizing profits and market share; that it requires visionary, charismatic leadership; and that it requires brilliant, sophisticated strategic planning. In general, these characteristics were no more likely to be found in the visionary companies than they were in the others; indeed, they were often entirely absent from the most successful companies, and so could not be implicated in their success at all.

So what *does* explain the difference? A key finding of the Stanford study reinforces and valuably amplifies our conclusion on the importance of a corporation's "inner voice." In each of their 18 visionary firms, Collins and Porras saw a set of core beliefs—an "ideology"—that had remained essentially unchanged over long periods and that had mobilized and inspired people at all levels of the organization. They found that in almost all cases the visionary companies had been motivated more by such beliefs and less purely driven by profit than the comparison firms, even though, paradoxically, they had been more profitable in the long run.

Collins and Porras insist that these core beliefs are unique to each company, that there is no "correct" version. Examples include dedication to serving the customer (Wal-Mart, Nordstrom); respect for individual employees (Hewlett-Packard); and innovation (3M). What matters is not correctness, but *authenticity:* the strength of the belief that this is what the company stands for and that this is how it should do business.

The Broader Lessons

THE GREAT FORCES OF CHANGE AT WORK IN THE ECONOMY TODAY hold tremendous promise not just for the owners of American

corporations but also for American workers and consumers. Yet the turbulent energies released in their wake are understandably also fueling unease and apprehension.

More than a billion workers in developing countries are projected to enter the global labor market over the next 20 or 30 years, with most earning only a tiny fraction of the average wage in the advanced economies. Some American workers, especially (but not only) the least skilled, are sure to be adversely affected. The vast armies of new workers and their families in developing countries will also present huge new opportunities for growth, of course—opportunities that large American corporations, well capitalized and sophisticated in the use of technology, seem well positioned to exploit. But the extent to which American workers will share in those benefits can only be guessed at today. Where will the investment go, and the jobs? And what will be the impact on the number and quality of jobs remaining at home?

The continuing rapid advance of information technology is creating equally profound uncertainties. The new digital technologies will open up wholly new frontiers of economic activity, making possible the delivery of products and services that are unimaginable today. They will also radically transform the way businesses collect, process, interpret, and distribute information—in other words, the way work gets done. (The re-engineering movement will be seen in retrospect as a primitive step in this direction.) But this great structural transformation is almost certainly still in its early stages, and it will be a time of dislocation and disruption, as obsolete economic structures are torn down to make way for the new demands of the information era.

Every economic change creates losers as well as winners, and for some the price of change will be high. But even many who stand to gain from these changes have come to equate them not with opportunity but with disruption and a loss of control over their lives. In America and throughout the industrialized world, the fear of rapid economic change has already brought increasingly strident calls for stringent regulation of corporate behavior, protectionist trade policies, and other expressions of populist sentiment.

These anxieties abated in the United States during the robust expansion of the 1990s, but they have not disappeared. They will gain new force when the economy turns down, as it inevitably will, and the pressure on policy-makers to do more to relieve the anxiety may then build dramatically. The risk is that the resulting policies will exact a very high price in terms of private investment abandoned or forgone. And that, in turn, would mean lower productivity growth, which, as I argued above, is the key to our future well-being. In a very real sense, then, the solution to the problem of productivity growth will depend on how much uncertainty ordinary people are willing to bear before a backlash against the forces of change sets in.

In dealing with this problem, I believe that we have something to learn from the companies that follow their "inner voices." Throughout these organizations there is a clear and concrete understanding of core goals and values, which helps employees remain focused on what needs to be done—even while everything around them is in flux. People know what they are doing, and why they are doing it.

In this respect, the employees of a company may not be so very different from the citizens of a country. Just as a strong sense of identity and of purpose beyond profit has helped the most successful companies navigate through confusing and unpredictable territory, a shared sense of *national* direction and purpose can help advance prospects for future growth.

Today, however, talk about shared purpose and economic values is largely absent from the national debate about growth. The debate is dominated instead by talk about how much growth to achieve, and how to achieve it. We are like one of the "non-visionary" firms mentioned above, paying lots of attention to the bottom line and not enough to what lies beyond it.

If people are to be persuaded to embrace change rather than resist it, if they are to be convinced of the need to live with the volatility and the radical uncertainty of the new economy rather than fight against it, they must see the possible benefits of such a stance. They must have a positive reason to open themselves up to economic forces that will sometimes seem arbitrary and out of control. They must, in short, have a sense of direction and purpose.

For many in the workforce, perhaps even the majority, the promise of greater material compensation and wider consumer choice will fill in only part of the picture. What is also needed, I believe, is a coherent vision of the place of work and learning in society and what the work experience itself might become for the majority of contributors to the new economy. At a time when so much is changing in the workplace, what are the basic principles—the core values—that should govern the employment relationship? What are the rights, responsibilities, and resources that should be accorded to those who will contribute their efforts to the new economy? How should we define this "New Economic Citizenship"? I do not have the space in this article to develop the idea fully (it is elaborated further in *The Productive Edge*). However, there are two aspects that I'd like to touch on briefly: those relating to information technology and to benefit structures.

The new information technologies that are transforming the workplace seem to have a Jekyll-and-Hyde aspect. To some they are job-destroying, occupation-reshaping, wage-polarizing, socially divisive wrecking balls. But that is far from the whole story. The same technologies can also offer unprecedented opportunities to move beyond the production systems of the past, systems that offered intrinsic satisfaction only to people at the top of the economic pyramid. Used well, these new technologies can eliminate much of today's narrow, repetitive work and provide personal and professional satisfaction to a far greater number of workers than ever before in history.

Which will it be? Not easy to say, because both outcomes—liberating or repressive—are possible. We may choose to use technology to diminish the human contribution: to pressure, to downskill, or to demean. Or we may choose to use it to augment human capabilities and enhance the work experience. The point is that such a choice exists—and it is one of the key issues at stake for our society in the debate about growth. Yet that choice is hardly acknowledged in the debate today.

By affirming and reaffirming the values that the new technology should serve—for example, by protecting rather than compromising the dignity of work, granting workers control over their working environment, and making it possible for their endeavors to be appreciated and appropriately rewarded—I believe that our society stands a far better chance of realizing the full potential of technological advance.

Beyond technology lies the issue of lifelong change and career

Boeing


RICH FISHMAN

One of the greatest gambles in aviation history, the development of the hugely expensive 747, like other Boeing projects before and after, was not really a response to a competitor, since no other company was then seriously entertaining such a project.

Boeing 747 under construction in Everett, Washington

development. Just as companies such as Levi Strauss put great stress on the possibility of their employees learning new skills and moving to new roles, our society needs to think hard about the fact that lifetime careers with a single employer are now very much the exception, not the rule. As in the case of information technologies, this fact has two quite different faces. For many people, the prospect of a multiple career path with multiple employers will seem daunting, a prospect to be endured rather than welcomed. That's the unpleasant face of change. But it is also possible to imagine a future in which individuals not only take on more responsibility for managing their own careers but also obtain more control over the resources needed to do this well.

This, I believe, is the larger implication behind current policy proposals for more portable pensions and benefits, such as health benefits, individual skill grants, tax-deductible individual training accounts—indeed, even the movement for greater parental choice of children's schools. All such proposals move in the direction of giving individuals greater control over what they need to manage economic and technological change. Anthony Carnevale, chairman of the National Commission on Employment Policy, argues that new career development and benefit structures, by promoting autonomy and private choice, would bring the world of work into closer alignment with our society's individualistic and participatory values. Carnevale and others believe that these offerings would offer a true alternative to the "standardized offerings of the welfare state on the one hand and the increasingly rare and uncertain embrace of corporate paternalism on the other."

DOUG KNUTSON

Core beliefs are unique to each company; there is no "correct" version. Examples include dedication to serving the customer (Wal-Mart, Nordstrom); respect for individual employees (Hewlett-Packard); and innovation (3M).

Workers at 3M Scotch tape plant in Hutchinson, Minnesota

These are certainly not the only aspects of a "New Economic Citizenship." Nor do I claim that they are the best of all possible proposals. I do believe very strongly, however, that these are the kinds of issues we should be talking about when we debate how to achieve stronger growth. Growth remains the central problem facing the American economy. But the question of how to achieve it cannot be divorced from the question of what it is *for*, of what kind of economy we want to build, of the values we care most about. In the final analysis, maintaining a healthy growth rate means maintaining a healthy relationship between industry and society—a relationship without which neither can survive, let alone thrive. The creations of modern industrial enterprise are a glorious living monument to society's powers of cooperation, ingenuity, and imagination. As we stand on the threshold of the new century, we have an extraordinary opportunity to harness those same powers, those same *values*, to the design of the new world of work. Our nation's future well-being may well depend on it.

The Big Dig

Fed up with notoriously bad traffic and the pollution and noise that go with it, Boston is hiding its highways underground—but what will it take to keep subterranean travelers safe?

BY SIMSON L. GARFINKEL

WHEN PRESIDENT DWIGHT D. Eisenhower signed the Federal Highway System legislation in 1956, he couldn't possibly have envisioned the behemoth construction project that is now being undertaken in Boston to complete the system. Government officials call it the Central Artery/Tunnel (CA/T) Project; locals just say "the Big Dig." By the time it's finished in 2004, this roadway will boast a segment eight lanes wide, 3.5 miles long, completely buried beneath the bustling financial district of one of the nation's oldest cities. The new tunnel will replace Boston's much-maligned Central Artery—a dilapidated steel viaduct that cuts between downtown high-rises—with a stretch of the world's largest underground highway. An underwater tunnel (completed in 1995) will feed traffic from the airport into the artery, all for the unprecedented cost of more than $10 billion.

Although burying the highway promises to leave an improved environment for Boston's surface dwellers—cleaner, quieter, more open—it raises the stakes for subterranean travelers. Traffic jams and flat tires, merely annoying above ground, can turn deadly below if motorists are trapped in a haze of toxic exhaust fumes. Add to the mix a car fire or an oil tanker explosion and the situation could become dire. So Big Dig engineers are pioneering new technologies in construction, traffic management, and fire control, all designed to keep life flowing smoothly and safely through the artery.

The Brains behind the Operation

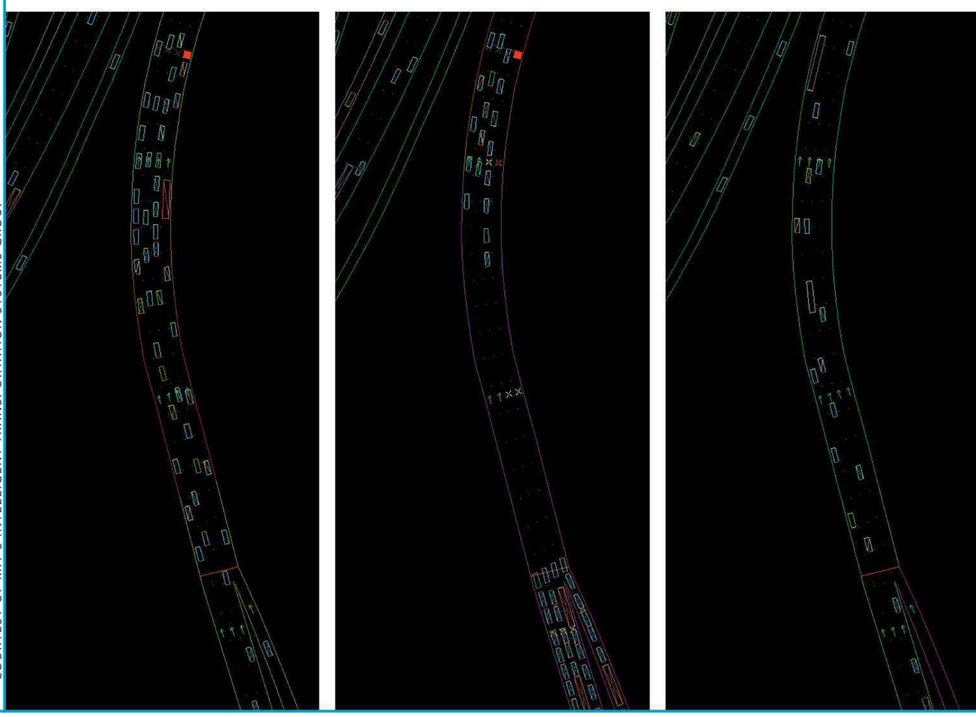
beyond laying steel and pouring concrete, Big Dig crews are deploying hundreds of closed-circuit television cameras, infrared

sensors, and variable message signs throughout the system, wiring it together with a computer system that can withstand a terrorist attack, and building a command center so filled with screens, keyboards, and projection devices that it would make Darth Vader green with envy. It's all part of the Central Artery/Tunnel "Smart Highway," or Intelligent Transportation System.

Working in the "Star Wars" control center, the CA/T's half-dozen human operators will strive to maximize traffic flow and minimize motorists' exposure to carbon monoxide. The tools at their disposal will include traffic lights, speed limit signs, lane closure signals, AM and FM radio transmitters, ventilation equipment, even sewage pumps.

The CA/T's computers will constantly monitor the flow of traffic through the system. If there is a sudden interruption—say the traffic in a lane drops from 60 to 5 mph—the computer will automatically swing a camera to point at the area in question. The computer can calculate the severity of the incident, designate an appropriate human operator to handle it (based on his or her training and current assignments), and make the video image appear at the operator's console. Then the computer will

UNDER CONTROL: A computer simulation can model common traffic situations. In the first panel, a car has just broken down in the tunnel (indicated by a red square in the top center). In the second, operators respond by closing lanes (yellow Xs) and the entrance to the tunnel (red line). The CA/T managers' goal is to have the incident cleared and traffic flow restored in a mere 15 minutes (last panel).



COURTESY OF MIT'S INTELLIGENT TRANSPORTATION SYSTEMS GROUP

PHOTOGRAPHS BY ANDY RYAN

COMPOUND EYE: **Operators in the "Star Wars" control center (above) can see every inch of the CA/T system. Along the highway 500 cameras feed images to a wall of monitors; when the computer detects a problem, it switches the video image to an operator's desktop monitor. The operator can alert drivers to lane closings and speed limit changes using variable message signs (below).**

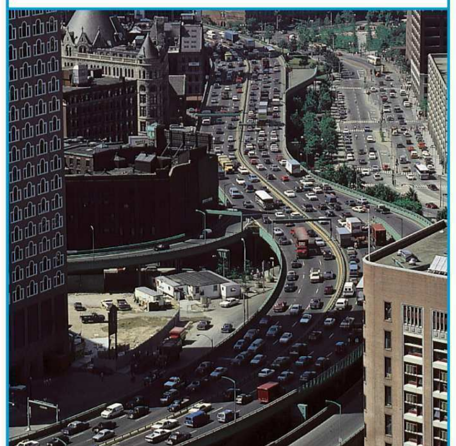
recommend a strategy for handling the situation, but leave the final decision to the human, who can change lights, adjust ventilation equipment, or send messages to drivers, all to prevent a minor fender-bender from becoming a major catastrophe.

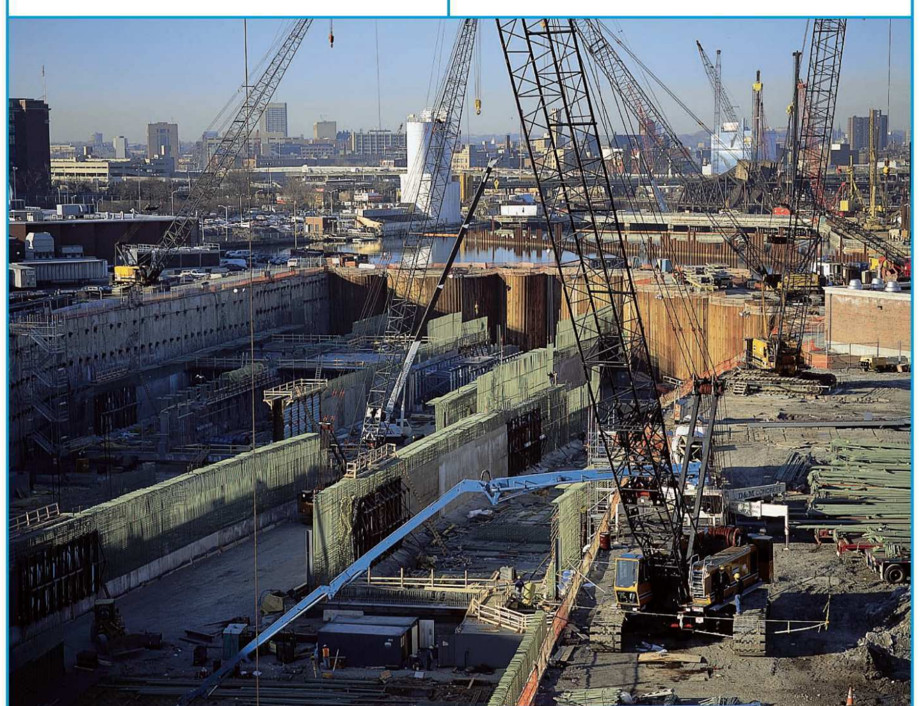
But what should an operator actually do in an emergency? Close lanes? Slow traffic? Divert traffic? And how long should lanes stay closed? To answer these questions, the Massachusetts Highway Department contracted with MIT's Intelligent Transportation Systems group (http://its.mit.edu/) to build an advanced computer simulation that models up to 10,000 vehicles moving through ramps and tunnels.

"We simulate the drivers' decisions such as acceleration, deceleration, lane-changing, merging, and yielding," says professor Moshe Ben-Akiva, who directs the MIT group. "We can simulate incidents by blocking lanes for a certain duration. We can simulate changes in

visibility conditions." The system can even determine the effect of closing exits or adding new ones.

Along with the traffic simulator, the MIT group has built a second simulator that models the CA/T's human operators and traffic management system. This lets the researchers see the effect that different traffic management strategies will have on the ebb and flow of traffic inside the tunnel. When there is an accident inside the tunnel, for example, the portal lights on the freeway immediately turn from green to red to prevent more cars from entering. Using the simulator, the researchers calculated how long the operators should wait after the accident is cleared before the portal lights are turned from red back to green. "The original plans to change the portal lights to green immediately was not a good idea," says Ben-Akiva. "You should delay the change until you let the traffic inside clear out. Otherwise, you generate shock waves of traffic inside the tunnel."



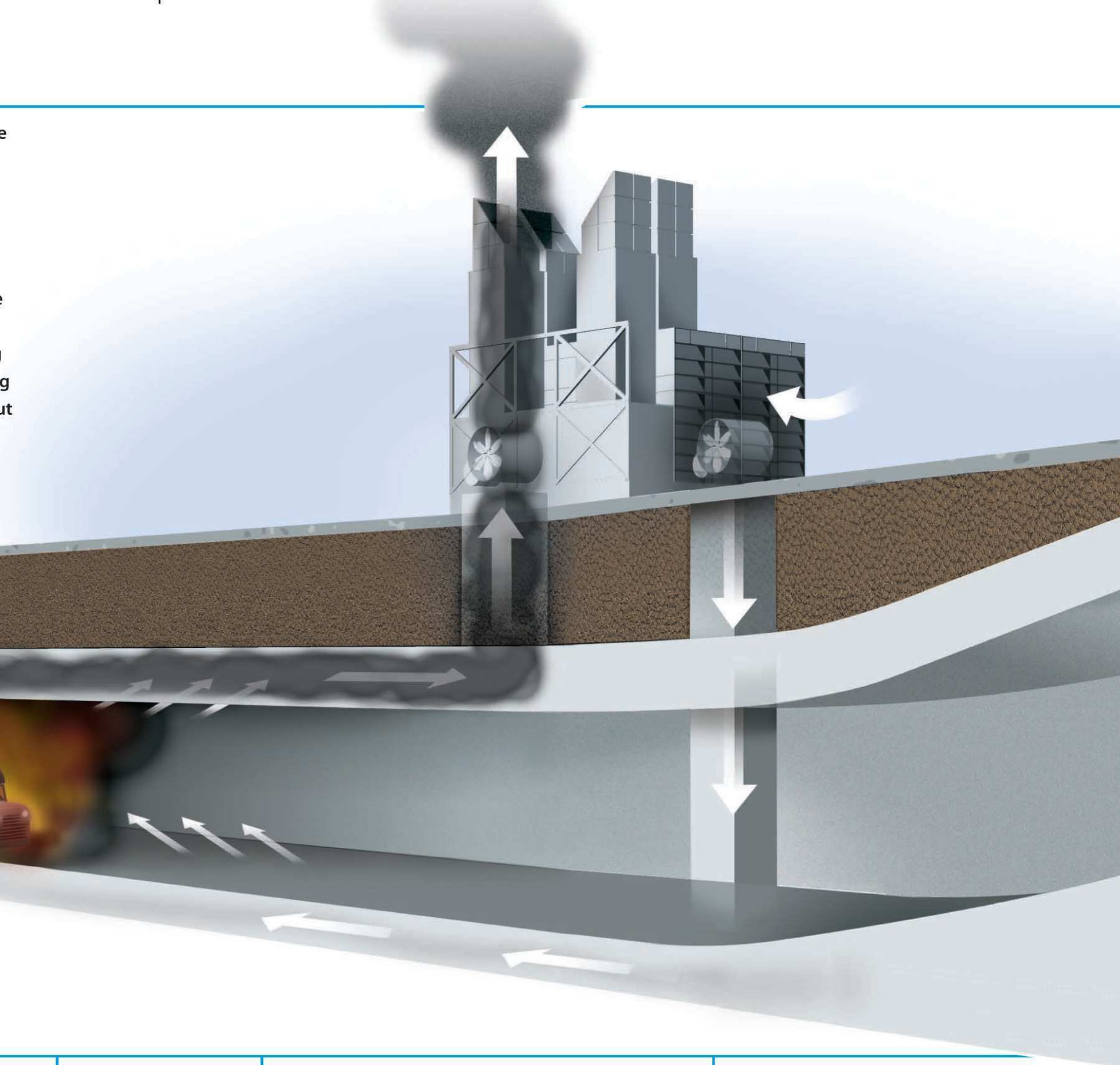


ARTERIAL BYPASS: Big Dig contractors are tearing down the elevated artery (above) and tearing up the urban landscape (below) to make way the new tunnel.

Fire in the Mountains

If ca/t designers and operators got some surprises when they began simulating traffic flow, they got even bigger shocks when they began to look into another problem: how to protect a tunnel and its occupants from the ravages of fire. It wasn't just the threat of direct burns that they were worried about. In fact, "Smoke and heat are the real killers in a fire," says Richard W. Drake, operations manager for the Central Artery/Tunnel Project.

For years, explains Drake, engineers around the world have been building automobile tunnels with ventilation equipment large enough to handle the smoke from the biggest fire conceivable. But they had no way of knowing how their conceptions of fire would match a real blaze. Though tunnel fires—such as the one that broke out in 1996 in the Channel Tunnel that connects the U.K. and France—capture international media attention, none has burned under the watchful eye of high-speed scientific instruments. So engineers have always based their fireproofing designs on theoretical models, not hard data.



FANNING THE FLAMES: Should fire break out underground, motorists' lives will depend upon seven mammoth ventilation buildings perched above the tunnel. Each structure will house 18-foot fans that draw fresh air in through the louvered sides of the building and pull smoke and fumes out of the tunnel. A series of experimental fires in an abandoned tunnel in West Virginia taught Big Dig engineers how best to operate fans during a blaze, allowing occupants to breathe without feeding the flames.

Uncomfortable with this uncertainty, engineers have for decades over-built their projects, adding more ventilation equipment, insulation, and structural support than they thought necessary—just in case their models underestimated the heat and smoke a tunnel fire could produce.

What engineers needed was a test bed—an experimental system for tunnel fires. And in the early 1980s, the Federal Highway Administration (FHA) came up with one, re-routing a section of I74 in a way that left an empty 1.1-mile tunnel in the hills of West Virginia. There the FHA teamed up with Parsons Brinckerhoff, one of Big Dig's primary contractors, to perform a series of full-scale burns that would finally put the theories about tunnel fires to the test.

The team spent $10 million renovating the abandoned tunnel with a state-of-the-art ventilation system and another $10 million installing sophisticated monitoring instruments. "We outfitted the tunnel on a grid system so you could collect data on temperature, air flow, and carbon monoxide throughout the tunnel," says Drake, who supervised the project.

In the middle of the abandoned tunnel the engineers built large steel pans measuring more than 10 feet on a side. They filled the pans with 6 inches of water (to protect the steel from the heat) and then an inch of fuel oil. A remote-controlled propane burner ignited the fuel.

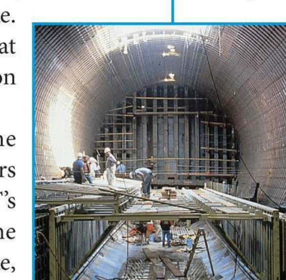
Ultimately, Drake supervised 101 burns. The smallest was 10 megawatts (MW), simulating a small car bursting into flames. The largest was 100 MW—approximately the power released when a small gasoline tanker has a head-on collision with a truck.

"If you want to see what Hell looks like, we'll show you a picture of a 100-megawatt fire," says Drake. "It is absolutely astounding to see tiles blown off the wall. The asphalt and tar expansion joints bubble."

To the team's amazement, the tunnel and the ventilation equipment held up far better through these holocausts than the models had predicted. "Nobody thought we would ever get this number of fires off. They thought the tunnel would collapse long before we were done with it," says Drake.

The resilience of the tunnel in West Virginia pointed toward a staggering conclusion: Worldwide, billions of dollars had been wasted making tunnels more fire resistant than was ever needed.

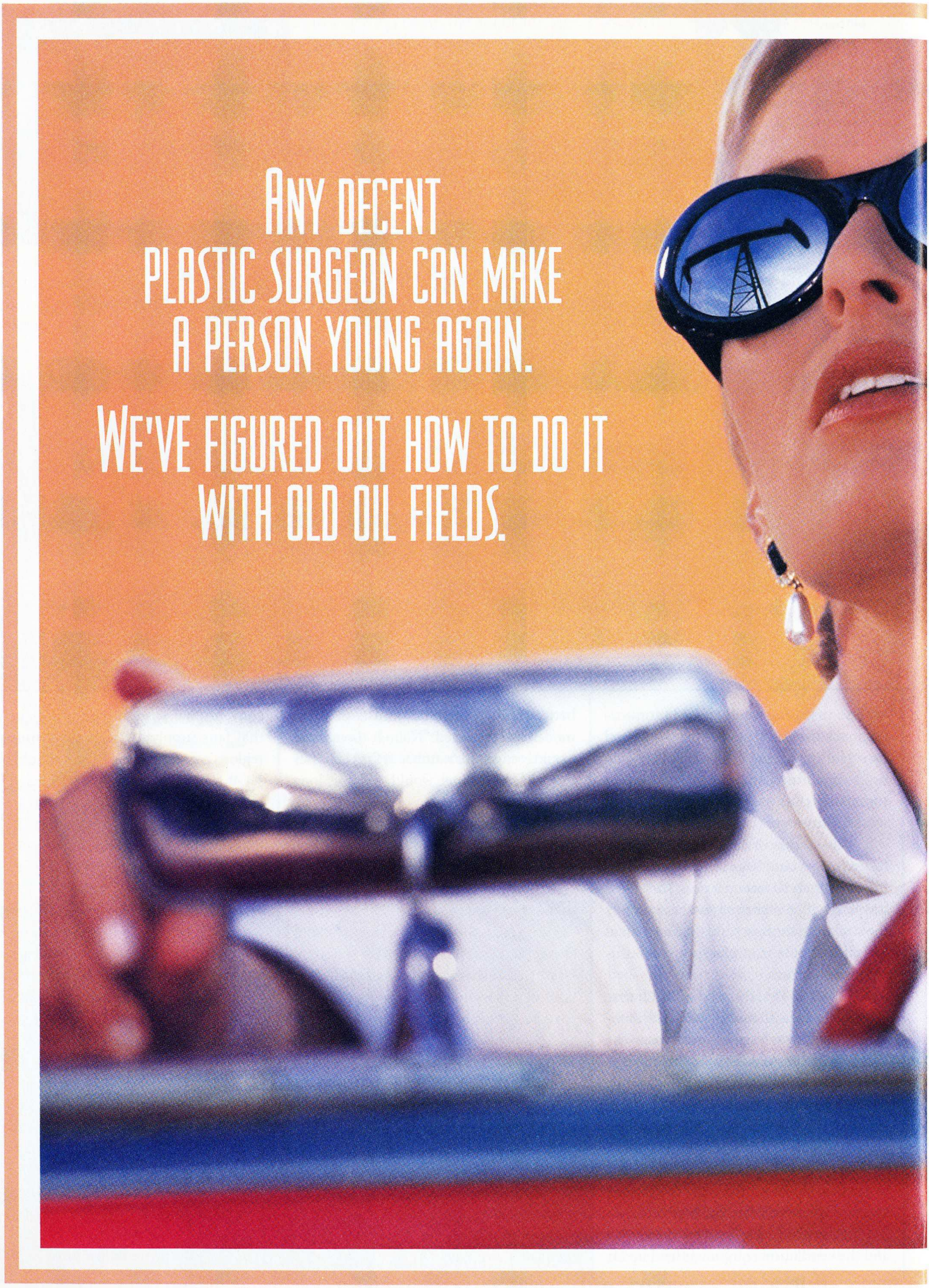
Although the results came too late to allow for a complete Big Dig redesign, Drake has still been able to save tens of millions of dollars in concrete and excavation costs by shrinking some ventilation shafts and eliminating others. "We saved about $25 million on this project in insulation costs alone," says Drake. "We are very confident that we can show you $45 million in savings overall."

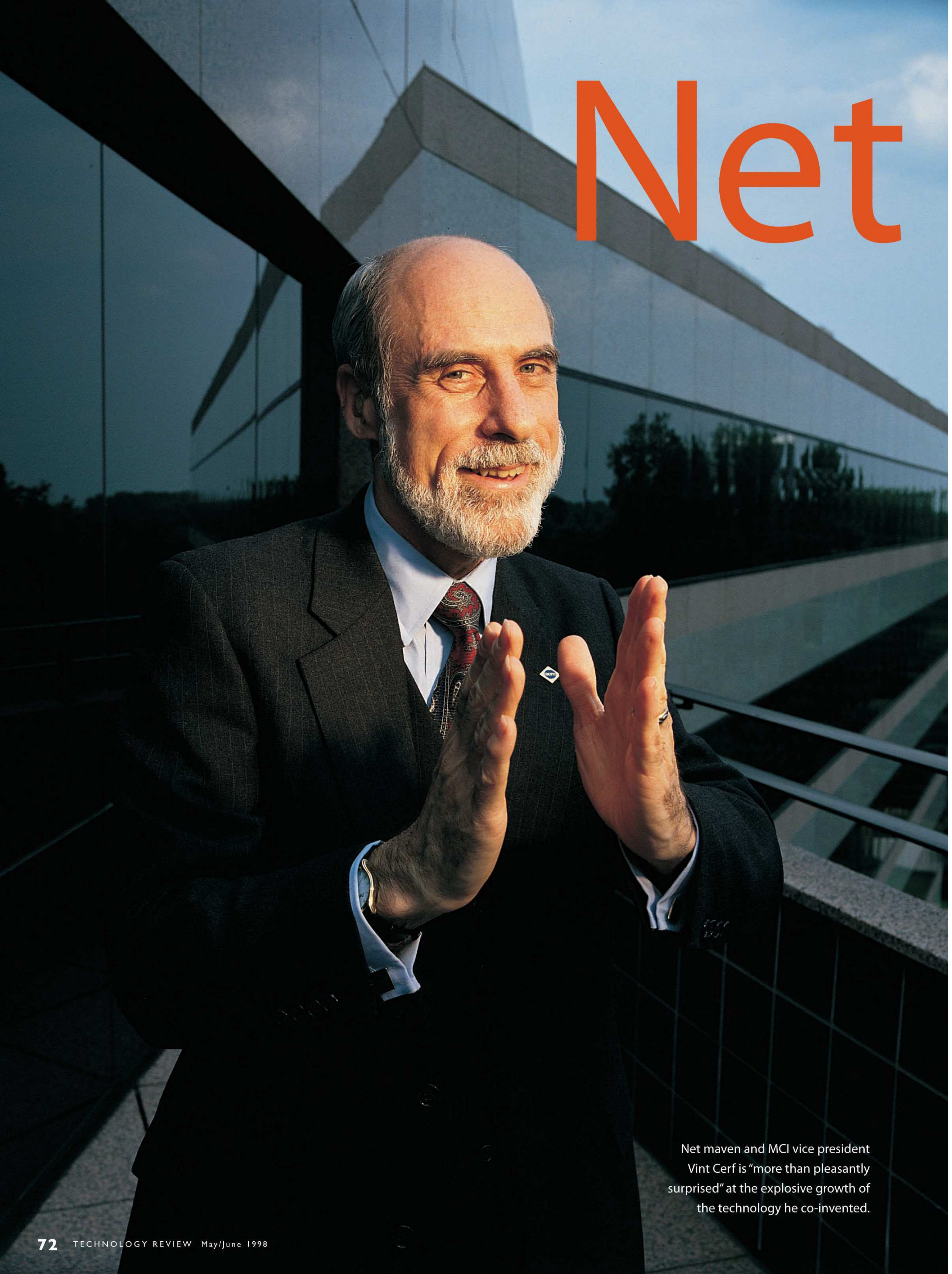


More important, the tests have taught engineers how to "tune" the CA/T's ventilation system. In the event of a fire, says Drake, conventional wisdom had always held that fans supplying fresh air to tunnel regions adjacent to the flames should be set at roughly 50 percent of capacity. It was an attempt to strike a delicate balance: "You don't want to feed fresh air" to the fire, explains Drake, but you don't want people trapped in their cars to suffocate either.

Again, conventional wisdom was wrong. The West Virginia experiments showed that it is better to turn the nearby supply fans way down during a fire—to just 10 percent or 20 percent of capacity. At these reduced settings, the tests prove, the ventilation system will still provide enough fresh air for trapped motorists, and it won't fan the flames as high. It's a strategic adjustment that might seem minor, but with a quarter of a million vehicles expected to negotiate the tunnel each day by 2010, its impact could prove enormous. TR

DIAGRAM BY DOUG STERN • PHOTOGRAPHS BY ANDY RYAN


ANY DECENT
PLASTIC SURGEON CAN MAKE
A PERSON YOUNG AGAIN.
WE'VE FIGURED OUT HOW TO DO IT
WITH OLD OIL FIELDS.



Net maven and MCI vice president Vint Cerf is "more than pleasantly surprised" at the explosive growth of the technology he co-invented.

Net Cerfing

Q & A

Vint Cerf, one of the Internet's founding fathers, eyes his child with pride and hope By Herb Brody

Every time you send an e-mail, surf the Web, or buy a product online, you are using the Net that Vint built.

Well, not all by himself, as he is the first to point out. Like most technologies of significance, the Internet flowed from the minds and work of many people. "There are countless others," he says, "who have spent their entire careers working to take the Internet where no network has gone before." But without the innovations of Vint Cerf, the whole idea of a global mesh of computers and people exchanging messages, pictures, and software could have gotten stuck on hold indefinitely.

The Internet works because of a method of sending information called packet-switching. Although he did not invent packet-switching, Cerf, along with Robert Kahn, formulated the packet-switching recipes that have become a worldwide standard. These protocols, known collectively as TCP/IP, are the common denominator that unifies the global Internet. The Net that we have come to know—including the World Wide Web in all its graphical and interactive glory—rests on this remarkably robust foundation of TCP/IP.

Cerf is much in demand as a speaker, playing the incongruous role of the Internet guru in a spiffy three-piece suit. He has a day job, too, as senior vice president of Internet architecture and engineering of MCI Communications. There, he oversees the development of network technologies and keeps a sharp eye on the progress of the technology he helped create. This is Cerf's second stint at MCI. During the 1980s, he helped create MCI Mail, a service that helped popularize the concept of electronic mail.

Because of his hectic travel schedule, Cerf prefers that interviews be conducted through e-mail. *Technology Review* Senior Editor Herb Brody held up TR's end of the computer-mediated conversation.

Photos by Katherine Lambert

TR: You are generally credited as being one of the "fathers" of the Internet. How do you feel about your child's success?

CERF: I've been more than pleasantly surprised over what's happened. I never anticipated that the experimental Internet would get larger than 128 networks—and we're long since past that now.

TR: What do you see posing the most serious threat to the Internet?

CERF: I'm most concerned about heavy-handed intervention to attempt to regulate the Net. Although the Supreme Court struck down the Communications Decency Act, some members of Congress are trying to revive similar legislation—a development we all should be concerned about. I've often traveled to Capitol Hill to brief Congress on the industry, and I'm struck at just how misinformed some members are concerning the Internet. Thankfully this is changing, although not as fast as I would like.

TR: In a sense the issue seems to be who should run the Internet.

CERF: Yes, and that has come to a head most recently in the debate over the administration of domain names. More than 100 companies have endorsed a new domain naming system developed by industry organizations. But the proposal was not universally accepted, and the White House undertook to develop an alternative that it hopes will gather broader support. These two proposals have similar objectives but differ in important ways. My sense is that each has positive elements and significant commonalities that should be used to form a foundation for a broad consensus on the whole issue. The critical next step is to move from talking (and flaming, for that matter), which has occupied us over the past year. We're running out of time, and both sides need to be ready to compromise for the greater good.

Too Much for Too Little?

TR: A few years ago, the Internet appeared to offer users an almost free lunch. Has that harmed the Net's development?

CERF: In some ways, it has. Because of its initial sponsorship by the U.S. government, many of the costs of the Internet have been hidden. As a result, some proponents of a cyberspace utopia persist in believing that the benefits of a wired world will somehow arrive at little or no cost. The fact is that technology advances in economically self-supporting increments. As subsidies have eroded, the costs they defrayed must be assumed by someone. That seems to be a lesson that some have conveniently forgotten.

TR: How is that evident?

CERF: One example is the "all you can eat" pricing plans for Internet access. This model works only if Internet access providers can predict total usage and can price

accordingly, or if they can place an upper bound on usage to achieve the same effect. It seems likely either that prices for unlimited access will gradually rise—witness America Online's price hike earlier this year—or that people will start paying some kind of usage-based fee.

TR: What about Internet telephony—that seems like another example of how the Net can provide a kind of free lunch.
CERF: Yes. A small but dedicated cadre of boosters often hail it as a low-cost alternative to long-distance telephony. But any near-term advantage will be temporary.

TR: Why?
CERF: The cost of a long-distance call depends heavily on the access fee that the local telephone exchange has to pay. Right now, long-distance voice carriers pay substantial fees per minute for the use of the local networks. Internet service providers, on the other hand, enjoy a fixed monthly price. These differences are likely to erode with time. Still, there may well be some economies arising from the packet-switched nature of the Internet that allow Internet telephony to operate more efficiently than circuit-switched telephony. And over the long term, the technology curve favors the Internet. The cost of routers and gateways will drop faster than the cost of telephone switches. In any case, the phrase "Internet telephony" is as helpful in describing the changes we're in for as "horseless carriage" was for foretelling the sea change engendered by the introduction of the automobile.

Tale of Two Tapestries

TR: In some ways, the Internet seems to be displacing the telephone network.
CERF: Think of the Internet and the Plain Old Telephone System, or POTS, as two tapestries hanging side by side. The Internet is dynamic and flourishing, while the phone system is venerable, ubiquitous, and reliable. Now imagine if we take these tapestries apart and reweave them together one strand at a time so the two are indistinguishable from one another. That's the future we're heading toward.

TR: I thought the Internet and telephone system coexisted pretty well right now. Data, voice, and video already share the same lines.
CERF: Yes, indeed, they travel over the same beloved fiber optic lines. What we don't have in place yet, though, are technologies that get POTS and the Internet to work invisibly and in concert, delivering the integrated services that the communications revolution has always promised but has yet to deliver.

TR: I still don't understand what exactly is lacking in the present system. From my desk at MIT I can make a phone call, send a fax, check my e-mail, and surf the Web—all pretty much simultaneously.
CERF: Yes, but integration will provide more seamless interaction. You could have a universal, multimedia "in-box" that can accept e-mail, voice mail, video mail, and faxes. That's not going to happen until the Internet and the phone system are blended better. By the year 2010, more than half of all voice traffic will be traveling over packet-switched networks. But for the great majority of users, placing a voice call over the Internet will be no different than placing a phone call today.

TR: What will we be able to do that we can't do now?
CERF: Say you're catalog shopping on the Web and you'd like to ask a specific question about a product you'd like to buy. Already, we're seeing applications that would let you make that call using the same Internet connection you are using to view the page. It might also allow integrated messaging, so that your pager alerts you when a particularly important e-mail arrives in your in-box. Services like these are being introduced for the corporate marketplace now. What will be really exciting is when they become available for widespread consumer use.

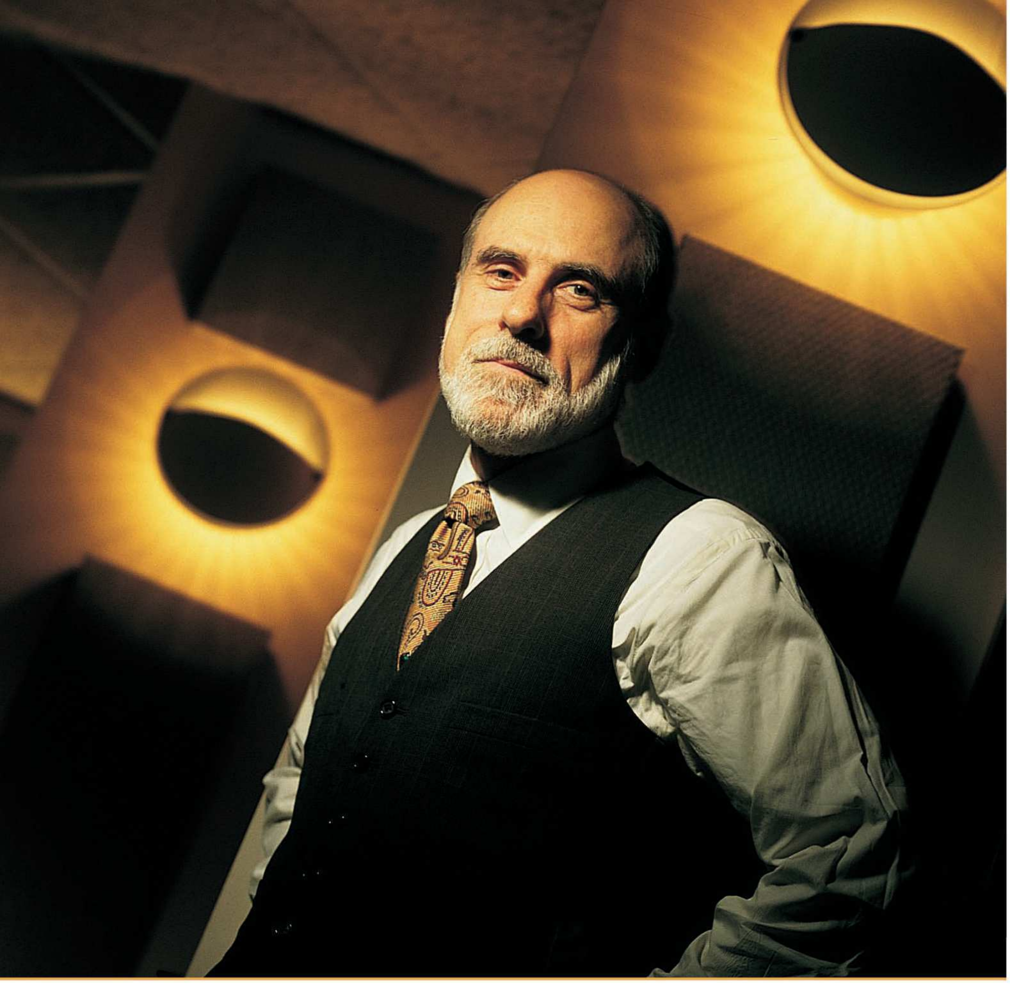
Multicasting into the Millennium

TR: What technologies do you think will change the way the Internet works?
CERF: One key development is something called multicasting, which vastly improves the ability to send real-time audio and video signals through the Net. The way things work now, a Web server has to send a new copy of the audio or video data to each individual who requests it. With today's technology, a high-end personal computer "unicasting" on the Internet serves a maximum of several hundred people simultaneously.

TR: What does multicasting do differently?
CERF: Imagine you'd like to share today's Dilbert strip with some of your colleagues working in a different building. You would not fax 10 separate copies—instead, you might fax one and ask a friend to make copies. Multicasting works along a similar model. A server sends only one copy of information, which can then be reproduced and distributed throughout the network.
TR: How might this be beneficial?
CERF: First, it reduces the unnecessary repetition of traffic on the network for material that needs to get to a large number of recipients at the same time. This applies, for example, to large-scale software distribution, database updates, and securities transactions information.

TR: How close is this notion to a reality?
CERF: Multicasting is already here. A number of Internet service providers, including UUNET, are offering multicast services. Last August, MCI and Real Networks announced the establishment of the Real Broadcast Network—an architecture that pushes information content to the periphery of the network and thus multiplies the potential audience dramatically. Before, a live concert that was broadcast on the Internet could reach an audience of only about 10,000 simultaneous users. The Real Broadcast Network makes it

I'm most concerned about heavy-handed intervention to attempt Capitol Hill and I'm struck at just how misinformed some members



to regulate the Net. I've often traveled to of Congress are concerning the Internet.

possible to fill a much larger "virtual stadium."

TR: Multicasting seems like a way to turn the Internet from a "many-to-many" network into a broadcast system. Won't that change the Net's character?
CERF: Yes and no. While we'll begin to see many broadcasting applications ported to the Net, we're not going to lose the many-to-many character that you and so many others appreciate. Also, it's not as if the Internet has never changed radically before. For many years, the Internet was almost entirely a text-based medium. The Web has certainly altered the character of the Net, but I'm not sure you hear much complaining—although we do need to pay a lot more attention to the presentation of Web content to people with limited sight and hearing.

The Ever-Evolving Net

TR: How can the Internet be changed to make it a better tool for business and commerce?
CERF: Well, there is nothing in the present structure of the Internet that isn't friendly to commercial transactions. Dell Computer reports sales of $6 million a day on their site, while Cisco Systems reports $2 billion per year on their own. Also, corporations are spending billions of dollars to create private intranets as a way to increase efficiency. Mass consumer spending on the Web seems to be in the early stages of lift-off. One very visible example is bookseller Amazon.com, which recently reported quarterly revenues of $66 million. That company grew to 700 employees in less than a year.

TR: What have you found most gratifying about the way the Internet has evolved over the years?
CERF: When I began my work, I was happy just to have packets travel successfully between points on the network. We didn't realize that we were developing a blank canvas that future technologists would paint upon with such broad and bold strokes. For instance, while we did do tests in the 1970s with transmitting audio and video, I never dreamed what we've seen develop over just the past few years. Today, in fact, we're seeing many types of media—most notably radio—being reborn on the Internet.

TR: Do you see lessons from innovations past to guide those who strive to refine the Internet today?
CERF: Look at the telephone. The underlying technology has advanced radically over the decades, but in one crucial aspect—the user interface—it has barely changed at all since the 19th century. So I think the most important technological innovations we will see with the Internet will be the ones that devise new interfaces to older services that are richer and easier to use than the simple but constrained interface of the telephone today. Of course, if we are successful with speaker-independent voice recognition, we may find a kind of renaissance in the use of voice as an interface to complex services.

TR: Put yourself 10 years in the future. What is it about the Internet in 1998 that will seem the most quaint?
CERF: The idea of having to dial a phone to make a temporary Internet connection—which is the way many people use the Net today—will seem pretty odd. We're going to evolve to the point where network access is provided like electricity—in other words, always on. Today, we use a circuit switch (telephone) to get to a packet switch (the Internet). In the future, we'll use a packet switch to get to a circuit switch—if we need the circuit switch at all.

TR: The Internet has gone from obscurity to near ubiquity in less than five years. That pace can't be sustained, can it?
CERF: Well, we are a long way from ubiquity. Only about 40 percent of all U.S. households have Internet access. In other parts of the world, the penetration is considerably less. Besides, nothing happens overnight—it only seems to. The Internet today is a result of many thousands of people devoting their entire careers to moving network technology forward, step by incremental step. When the Internet burst into the public consciousness, it was the culmination of a process that began in the 1960s. Looked at that way, the rate of change isn't necessarily unsustainable.

VIEWPOINT | By Gary Taubes

Telling Time by the Second Hand

It was with a perverse sense of familiarity that I read in the daily papers in January that catastrophe was once again on the way. "If a huge asteroid crashes into the middle of the Atlantic Ocean," wrote Pulitzer Prize-winning reporter John Noble Wilford in *The New York Times*, "say goodbye to Broadway, the beach house on Long Island and just about everything else on the East Coast as far inland as the foothills of the Appalachians." *Washington Post* reporter Kathy Sawyer was in a similar funk: "While the economy is booming and there are no major wars," she wrote, "scientists have come up with something to fill the worry gap: If a space rock three miles in diameter slams into the Atlantic Ocean, it would produce a towering, high-velocity wave that would swamp most of the upper East Coast."

This "revelation" came from researchers at the Los Alamos National Laboratory, who apparently had too much supercomputer time on their hands—what with the downsizing of the nuclear weapons programs and the disappearance of Star Wars—and so had run simulations on a one-in-ten-million-years asteroid plunking into the Atlantic. The Los Alamos public relations people knew a good story when it fell from the heavens and had thrown a press conference to announce the results.

The ensuing articles were further work in a genre that can be called "Death from Above" stories, after a phrase made famous by the best-selling science writer Timothy Ferris in a *New Yorker* article of January 1997, that the editors, alas, saw fit to run as a tie-in to an upcoming television disaster movie of the same ilk. The gist of "Death from Above" stories is that asteroids and comets could do to us any day what they apparently did to the dinosaurs. While there are reputable scientists who confess to losing sleep over this, they will admit, if pressed, that in the recorded history of humanity *no* human being has ever been shown to have been killed by an incoming astronomical object.

"Death from Above" stories make good copy, but they are hardly science. On the contrary, they are pedagogical examples of the relationship between science and the press, which can be described as one of mutually exclusive philosophical challenges. Put simply, the role of the daily press is to report the news, which is by definition what's new. The job of the newspaper science reporter is to write up the implications of the latest scientific paper—i.e., the one that officially comes out today—although only if the paper is sufficiently at odds with conventional wisdom or has some commentary on the human condition, which means sex, health, sports, aging, or money.

This, however, is fundamentally at odds with the nature of science, which is to establish what constitutes reliable knowledge and does so in fits and starts—false starts, generally, since most of them are either wrong or meaningless. In August 1996, for instance, when NASA scientists announced that they had discovered signs of life in meteorites that had apparently come from Mars (the genre here might be dubbed "We Are Not Alone" stories), a good bookmaker would have put the odds of them being right at 1000-to-1 against, because there were so many ways the researchers could have misinterpreted their data, and so few ways (one) that they could have had what they said they had. Remarkable results, after all, demand remarkable evidence, and the NASA data were decidedly unremarkable. The science reporters covered the story with the complete lack of skepticism it demanded if the goal was to keep it on the front page for a few weeks. Within six months it was obvious even to employees of NASA that the apparent signs of life were most likely artifacts of the experimental technique.

The role of the daily press is fundamentally at odds with how science proceeds, which is in fits and starts—most of them either wrong or meaningless.

John Ziman, a physicist and philosopher of science, has suggested that the front line of scientific research, where reporters make their livelihood, is simply not the place to find reliable knowledge. He describes it aptly as "the place where controversy, conjecture, contradiction, and confusion are rife." He quantifies his point by suggesting that the physics in undergraduate textbooks is 90 percent true, while that in the primary research journals is 90 percent false.

I once did my own calculation to this effect: In 1987, back when high-energy physics was still a viable field of research, I wrote an article for *Discover* magazine in which I tabulated all the discoveries in the field that had made *The New York Times* over the preceding decade. In nine of 12 cases the researchers had "discovered" something that turned out not to exist. The

BRIAN CRONIN

three discoveries that panned out were predictions of a theory that had been repeatedly validated and was already sufficiently conventional to be called the Standard Model. Not surprisingly, the nine errors were the more interesting claims, which means the better stories, because they were all at odds with the Standard Model or extended it deep into the unknown.

In good science, error is simply part of the game. No progress is made without it. "Science thrives on errors—cutting them away one by one," is how Carl Sagan put it. "False conclusions are drawn all the time, but they are drawn tentatively. Hypotheses are framed so they are capable of being disproved. A succession of alternative hypotheses is confronted by experiment and observation. Science gropes and staggers toward improved understanding." Michael Ghiselin, a biologist and MacArthur Fellow, describes error as part of the overhead of doing research. "The best scientists," he suggests in his 1989 book *Intellectual Compromise, The Bottom Line,* "can even be expected to make more mistakes than do the mediocre ones, for the best scientists do the most research. It is they who will work on the most difficult problems, and venture into the areas of greatest risk."

The challenge for the science reporter is how to deal with the onslaught of fascinating—and quite likely erroneous—results. At times this chronic problem shows up in an acute episode like the infection known as cold fusion. In 1989, during the three months of hysteria surrounding the outbreak of cold fusion, a then-*Washington Post* science reporter described daily science reporting, especially during such periods of extreme activity, as akin to playing goalie in a hockey match. Pucks come whizzing at you fast and furious, he said, and most you block, but a few get by.

WHAT IS THE SOLUTION? THE SCIENCE REPORTER CAN hedge his bets through the liberal use of caveats, but the editorial philosophy of daily newspapers works against caveats. When reporters add them to a story, editors are likely to move them to the end. Once at the end, the caveats can be easily cut when editors find themselves short on space.

Another way around the problem of sorting the seed from the husks is for the reporter simply to throw up his hands and say, "It's not my job, man." My favorite recent example of the lack of concern that some reporters attach to publishing bad science is that of the *New York Times* reporter who allegedly told a government expert on nuclear waste technology that his

job as a reporter was not to decide what's good science and what's bad, but what's a good story. (I say allegedly, because the *Times* reporter refused to speak on the record when asked to confirm or deny the remark.) He then went on to write a front-page *Times* article on a Los Alamos researcher who had concocted a theory that the proposed nuclear waste dump at Yucca Mountain might someday undergo a nuclear explosion. The buried radioactive waste would simply have to leach from its containers and form itself into a bomb with the help of natural forces. This required, in effect, nearly divine (or perhaps satanic) intervention. The *Times* reporter, however, did make sure that no pucks would slip into the net from behind by adding the requisite caveats and suggesting that even if the work was simply wrong (which it was) and could be debunked (which it would be), "the existence of so serious a dispute so late in the planning process [for the repository] might cripple the plan or even kill it." It was the one irrefutable statement in the article.

The best way, however, for science reporters to deal with the problem of giving publicity to the erroneous is to rely on experts. As Ghiselin puts it: "In the popular press, we are always reading that 'most scientists believe' such and such. Who cares what most scientists believe? We want to know what the best ones believe, especially those in the best position to evaluate the topic at issue." This last clause is a kicker. Most science reporters have their share of reliable researchers whom they consider experts, but it's unlikely that any one of these will be an expert in the precise discipline of the latest research. What's more, the more spectacular the announcement, the more likely that a scientist's expertise will become problematic. If the discovery is truly revolutionary—which is to say, paradigm-busting—then by definition any scientist on the "wrong" (conventional) side of the paradigm is likely to lack sufficient expertise to understand all the ways the reported work is likely to be wrong.

Consider the cold fusion episode. Within three weeks of the purported discovery of room temperature nuclear fusion by researchers at the University of Utah, the pursuit had devolved into a nuclear version of the emperor's new clothes. On one side were those scientists who believed Nobel laureate Luis Alvarez's adage: "Only trust what you can prove." They pointed out repeatedly that no reliable data existed to support the claim of cold fusion—let alone prove it—and that certain fundamental experimental procedures had been consistently ignored. The press treated these scientists as being firmly entrenched on the wrong side of the "new" paradigm. After all, most of them were nuclear physicists who had spent long years *not* discovering cold fusion; therefore they must be jealous. The rest of the skeptics were chemists, also tarred by their failure to discover cold fusion. That they did not embrace the new finding could only be because of hopeless self-interest.

Judgments like these render science reporting on most controversial subjects perilously close to anti-intellectualism. Science reporters tend to be fans of science who sincerely want to believe that there was once life on Mars, or that fusion power can be achieved in a glass of water. The experts have been trained to be critical, and they are easily seen as the arrogant eggheads we all disliked in junior high school. Non-experts quickly emerge to fill the vacuum, and they become invaluable resources to the reporter. Not only can you find a huge number of non-experts on any given subject, even a new one, but they are considerably more willing to give a bogus idea the benefit of the doubt, particularly if they stand to get funding to pursue research on the subject should funding agencies decide to go that route.

Although it would help if science reporters and their editors were more skeptical and relied more heavily on *real* experts, I'm not hopeful that the press/science paradox can be resolved. Indeed, because the press is primarily interested in the unconventional and the spectacular ("Man Bites Dog!"), it will always be easier to get press with bad science than with good. Bad science is inevitably more sensational than good science. Bad science has no boundaries: researchers can be sensationally wrong in an infinite variety of ways, whereas they can be right only in ways that are severely bounded by reality.

This is why even high-end journalism favors bad science: Bad science is the better story. So it is that a Princeton engineer who does ESP research gets five pages in *The New York Times Magazine*. A pair of Florida researchers who suggest that AIDS can be carried by insects, even though the disease doesn't fulfill any of the requirements for a vector-borne disease, can get eight pages in *The Atlantic Monthly*. A theory that electromagnetic fields from power lines can cause cancer, even though the theory defies the known laws of physics and much of what we know about biology, can get 100 pages in *The New Yorker*. And these are the most literate publications in the country.

But if science writers can't afford too much skepticism for fear of losing their jobs, readers, at least, can afford to be skeptical—and should be. As for me, I try to get through the morning papers by reminding myself of an old saying about the press. It goes something like this: "Trying to tell what's going on in the world by reading the daily newspapers is like trying to tell what time it is by looking at the second hand of a clock." TR

If science writers can't afford too much skepticism for fear of losing their jobs, readers, at least, can afford to be skeptical—and should be.

Low Road to Market

Determining the stage of a patient's tumor—and not more glamorous prognostications—may be how the highly touted "gene chips" enter the clinic.

DAVID ZADIG

SCIENCE WRITERS HAVE EXPENDED A GREAT MANY words on "gene chips," which are being touted as biological crystal balls that will diagnose future genetic susceptibility to disease. Having contributed my share of adjectives to this futuristic vision, I know how tempting it is to describe.

But technologies often travel the low road to widespread use, and while prognostic gene chips may well be a routine feature of annual physical checkups in the future, a related chip application has already entered the clinic through the back door. "Molecular profiling" is one name this technology goes by, and these highly precise genetic tests do not exactly predict the future. Rather, these chips assess the molecular stage of a patient's disease, and may ultimately suggest which drugs the patient might respond to.

It takes a genetic disease to beget a genetic test, and one of the most inviting targets—for marketing as well as molecular reasons—is a tumor-suppressor gene known as p53. Even in this frenzied "Gene-of-the-Week" era of biological discovery, p53 is a legitimate cover boy for the genetics of cancer, having earned the appellation of "Molecule of the Year" from the journal *Science* in 1993 and later appearing on the cover of *Newsweek*.

The reason for this celebrity is that the p53 gene, in its normal and intact state, plays the bouncer inside the velvet rope of a cell, mindful of the slightest aberrant behavior, such as the unchecked replication typical of cancer cells. The gene essentially orders a disobedient cell to commit suicide, which is an excellent biological way to suppress the rise of incipient tumors. Tumor cells grow better when p53 is inactivated by mutations, so there is strong Darwinian selection for cancer cells that shut off p53. Indeed, fully 50 percent of all human cancers are marked by disabled p53 function, including major killers like lung, breast, and colon.

Given its importance, clinicians would like to know the p53 status of every tumor they're trying to treat. About two years ago, biochip-maker Affymetrix joined forces with Oncormed, a cancer diagnostics company based in Gaithersburg, Md., to make p53 testing one of the prototypes of chip technology. Their target: the coding region of the human p53 gene, which possesses 1,262 base pairs of DNA—the chemical subunits of the double helix that tell a cell how to make the p53 protein.

Affymetrix, based in Santa Clara, Calif., has created a p53 chip that measures slightly less than 13 millimeters square—bigger than a thumbtack, but smaller than the standard issue 32-cent stamp. Engineers at Affymetrix have subdivided this real estate into a checkerboard of 20,000 "probe cells," each bristling with a uniform carpet of millions of identical DNA probes measuring 18 base pairs long. Using fluorescently labeled reagents, prepared DNA from a tumor can be washed over the chip, and extremely sensitive scanners are programmed to detect minuscule variations in intensity in the checkerboard pattern—which arise from slight genetic changes in p53. Once the DNA has been prepared, the test can be done in four hours.

Although p53 is only one of numerous genes implicated in the evolution of a tumor, it has already been thrust into a prominent role in experimental cancer treatments. In April of 1996, for example, Oncormed began using the Affymetrix chip to perform "molecular staging"—that is, assessing the status of a tumor—in patients with head and neck cancers prior to clinical testing of an experimental form of gene therapy developed by Onyx Pharmaceuticals. The therapy is in Phase II testing, and some patients have responded favorably in preliminary results.

The ability to do molecular profiling, according to Leslie Alexandre, a vice president at Oncormed, allows oncologists to determine both the virulence of a tumor and the extent of its metastatic spread. "If there is a p53 mutation in the tumor," she says, "then you would look at the lymph nodes and look for the fingerprint to see how far the tumor has spread." Oncormed has reached agreements with Rhone-Poulenc Rorer and Schering-Plough to do p53 testing associated with gene therapy trials.

The potential significance of such testing goes well beyond staging individual tumors. Drug companies are intensely interested in ways of predicting which patients are likely to respond to chemotherapy, and there is some evidence that p53—and molecular profiling like it—may help identify patients likelier to respond. Not only will this allow drug companies to achieve higher response rates in drugs being tested, but it may, Alexandre says, provide a way to "resurrect" drugs that fail in Phase III trials by identifying a small group for whom the drug is very effective.

As with many new technologies, there may be a social cost to molecular profiling. The most precious resource available to any cancer patient is not money, but hope. Tests based on the p53 chip and related chips may turn out to be one more sophisticated, definitive, and molecular way of telling a patient there is no hope. TR

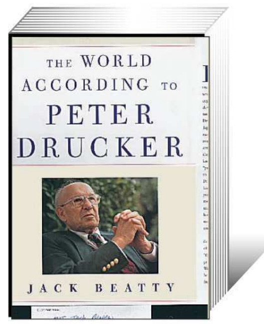
REVIEWS BY WADE ROUSH

The Moses of Management

NO PASTOR PREACHING to a congregation of CEOs could get far in his sermon without quoting from the scripture of Peter Drucker. Now that Jack Beatty, a senior editor at *The Atlantic Monthly*, has assembled a concise guide to Drucker's published works—from *The Concept of the Corporation* in 1945 to 1993's *The Post-Capitalist Society*—it's easier than ever to see how Drucker acquired his reputation as the Moses of management.

As Beatty explains, Drucker was the first to see that in the modern economy corporate executives could no longer try to be Andrew Carnegies, personally overseeing entire industrial empires. Modern managers must instead focus on setting goals, organizing, motivating, communicating, measuring performance, and developing people. Only thus, for Drucker, can constant social and technological change be harnessed as innovation (what he calls "organized change"). If this sounds old hat, it's because corporate America has so extensively absorbed and built upon Drucker's ideas. As Beatty puts it, "Drucker's gift is to create concepts that light up problems and possibilities; others, by his light, can see the new solutions."

Beatty's own gift is to draw out themes unlikely to be noticed by Drucker's less thoroughgoing readers. "First and last," he unexpectedly reveals, "Drucker is a moralist of our business civilization," fitting his insights into corporate culture within the larger frame of his own hopes and frustrations about the course of 20th-century capitalism. From the first, Beatty says, Drucker could see in America's workers the same kind of alienation that Marx had predicted would fuel revolution.The younger Drucker hoped that enlightened management practices—giving workers a guaranteed lifetime income, for example—would defuse this danger and reinforce a weakening social fabric. But due in large part to shortsightedness among both management and labor, Drucker's dream of stability for industrial workers has never taken hold. A somewhat disillusioned Drucker writes today that workers must be free agents, expecting little loyalty from, and owing little loyalty to, their employers.



THE WORLD ACCORDING TO PETER DRUCKER
by Jack Beatty
Simon & Schuster 204 pp. $25

Admiring without being sycophantish, Beatty's survey of the world as Drucker sees it—and as he would like to see it—makes enlightening reading. It's also pleasingly brief, as any good sermon should be.

A Netizen Tells Stories of Cyberspace

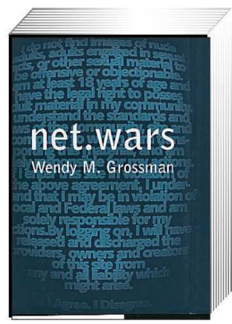
These days, a fully-wired citizen of the Net need never set foot in a grocery store, a bank, a bookstore, a post office, or a coffee shop. It would simplify things if all of the social and legal conventions of these old offline institutions could be smoothly imported to the new online ones, but as with most momentous technological transitions, it's not that easy. Now, from a journalist who is also a participant in the online revolution, comes one of the first comprehensive reports on the upheavals underway in cyberspace.

Wendy M. Grossman is an American who writes from London for publications such as *New Scientist* and also moderates a Compuserve forum for UK journalists. *net.wars* chronicles the Internet's evolution from 1995 to 1997, a period marked by vicious "boundary disputes," as Grossman terms them, over issues such as encryption and privacy, sex and sexism, and copyrights and censorship.

Grossman declares up front that she is too thorough a "Netizen" herself to be an objective storyteller, but the cultural and technical savvy she brings to her stories are far preferable to the naivete of the uninitiated. She also admits that she loves "the fact that in this age of polite political correctness there is a place in the world where people feel free to speak their minds, even offensively," and fears that overhasty government regulation threatens to undermine this freedom. But a journalist can be forgiven for advocating free speech.

In one representative chapter, Grossman reports on the Church of Scientology's crusade, in the name of copyright protection, to quell criticism of its theology on the Internet. In 1995 the church sued one critic for distributing documents on advanced church doctrines via the contentious Usenet newsgroup *alt.religion.scientology*. The church said the documents contained "trade secrets," and not only attempted to have the critic's Internet account stripped but also tried to have the newsgroup itself banned from all Internet computers, efforts that succeeded only in magnifying the online debate and the spread of the documents. In Grossman's perceptive rendition, the tale has two conflicting lessons, one about the new vulnerability of intellectual property to unauthorized distribution via the Net, the other about individuals' new ability to expose private information that may be in the public interest.

Grossman writes plainly yet entertainingly, providing a pleasant antidote to the breathless rhetoric one finds in many books and magazines devoted to computer culture. But what ties the book together is Grossman's demonstration that the boundary disputes have more to do with power than with decency or etiquette. The Net gives all its users a vastly increased power to communicate. How much of this power, she asks, will average users be allowed to keep?



net.wars
by Wendy M. Grossman
NYU Press 232 pp. $21.95

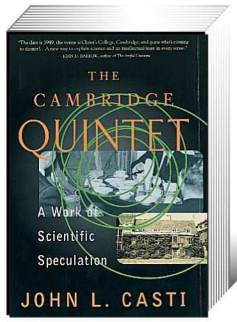
Brandy, Cigars, Machine Dreams

WILL COMPUTERS EVER become thoughtful enough to earn personhood? Fifty years of experimentation and debate have brought researchers no closer to a consensus on the issue, perhaps because it crams a vexing scientific question—What is a thought? —up against an even stickier philosophical and ethical one: What is a person? In *The Cambridge Quintet*, physicist-writer John L. Casti enlists five of the century's most distinguished intellectuals as the *dramatis personae* in a heated, hypothetical dinner conversation exploring this fault line.

Under Casti's direction, the characters add as much to the fun as the subject matter. The dinner is set at England's Cambridge University in 1949, and the host, appropriately, is the physicist and novelist C.P. Snow. Arguing for the plausibility of artificial intelligence is Alan Turing, the introverted mathematician and World War II codebreaker. Turing outlines for his colleagues the proposition (now famously known as the Turing test) that any machine with conversational skills indistinguishable from a human's must be regarded as intelligent, no matter how "programmed" this behavior may be.

Across the table, and across a vast ideological gulf, from Turing is the philosopher Ludwig Wittgenstein. At dinner, as in his writings, Wittgenstein posits that the essential medium of thought is language, and that language is based on culturally shared rules. With no culture or experiences of their own, Wittgenstein declares firmly, even machines capable of passing Turing's test would not be persons, and would have no genuine understanding of the words they used; "They may have machine dreams," he fumes, "but those dreams are as far from being the dreams of a human as a steam shovel is from being the college gardener digging in the courtyard."

Geneticist J.B.S. Haldane and physicist Erwin Schrödinger, as the last two dinner guests, bring some much-needed empiricism to this metaphysical dispute. This is no costume drama, however, and Casti doesn't limit his characters' scientific perspectives to those available in the late 1940s. Some of Noam Chomsky's ideas about the deep structure of human language, for example, find their way into Turing's mouth, while Wittgenstein brandishes John Searle's notorious Chinese Room argument against the validity of the Turing test. In this way the dinner recapitulates AI's own history since 1949, with agreement about the prospects—or even the criteria—for machine intelligence ever receding into the distance. Casti's book provides newcomers with a thorough and accessible introduction to the conflict, and veterans with a thought-provoking review—all enlivened by good company and good food. The real guests are Casti's readers.



THE CAMBRIDGE QUINTET:
A Work of Scientific Speculation
by John L. Casti
Addison-Wesley 181 pp. $22

Needs We Didn't Know We Had

IF CUSTOMERS DIDN'T HAVE TO CARRY all their purchases in hand-held baskets, grocer Sylvan Goldman realized in 1936, they might buy more. He invented the shopping cart—and became the father of the modern supermarket.

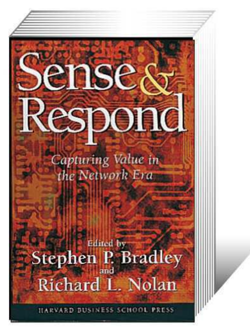
Meeting needs that consumers don't yet know they have is still the key to success in the free market, agree the contributors to *Sense & Respond*. But in today's competitive, seemingly saturated markets, would-be Goldmans need much more information to be able to innovate successfully, according to this group of academics and business managers. And help, they assert, has arrived just in time—in the form of cheap, powerful information-sharing networks such as the World Wide Web.

In the book's vision, the breadth and connectivity of the Web and related information technologies will enable lumbering old "make-and-sell" businesses, weighed down by lengthy product-development cycles and ritualized mass production, to take wing as flexible "sense-and-respond" organizations that electronically monitor consumer preferences and, with the help of their own internal networks, swiftly redesign their products and services to match. The Web can also act as the 21st century's shopping cart, vastly increasing consumer choice and convenience.

Several chapters, however, take a hard look at the uncertainties faced by organizations hoping to profit from this transformation. Contrary to media hype, for example, the book warns that the United States isn't a nation of technophiles; the products that dominate the new "multimedia" industry will be those that offer the clearest economic advantages to consumers—and require the least actual change in their behavior.

Oh, and it helps if they set the industry standard. Microsoft, not surprisingly, makes frequent appearances in the book, both as a sterling example of the modern sense-and-respond organization and as one of the likeliest winners in the multimedia race. The company scrapped its rigid, top-down, highly tardy software development procedures in 1990, we learn, and started treating product specifications as fluid and incorporating many rounds of customer feedback. That meant all wasn't lost in late 1995, when the company recognized the commercial significance of the Internet and swiftly brought out its own browser, Internet Explorer, to rival Netscape's Navigator.

Of course, the old make-and-sell companies aren't headed for the guillotine quite yet; my copy of Internet Explorer 4.0 is so bug-ridden that it regularly hangs my computer. But no responsible manager can deny that networked multimedia technologies are already transforming customer relations, even if it isn't yet clear where profits are to be had. *Sense & Respond* brings some sense to this revolution.



Sense & Respond: Capturing Value in the Network Era
edited by Stephen P. Bradley and Richard L. Nolan
Harvard Business School Press 339 pp. $45

No Site Is an Island

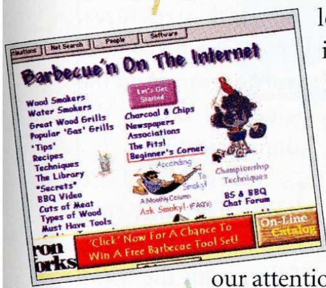
One journey's trail of clicks

By Herb Brody

WHAT THE WORLD REALLY NEEDS IS another magazine column advising its readers of hot (or is it cool?) places to go on the World Wide Web.

Yeah, right.

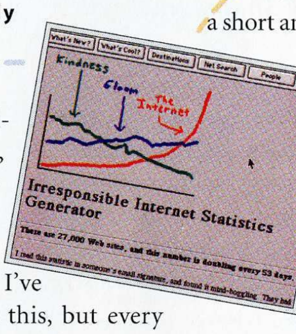
Most Web users have bookmarked numerous sites they wish to return to again and again. Places they're comfortable. Places they find visually and intellectually engaging. Places that don't take eons to load. But the Web is not a scattering of electronic information islands. It is a way of moving our minds, of creatively shifting our attention. The experience can be encapsulated not so much in where we've been but in the twisting, turning, backtracking, non-intuitive route we've followed.



That's the idea behind Web Crawl—I will provide you with the electronic footprints of one journey I've made on the Web, telling you which sites I've visited and how I got there. I hope that as I click, scroll, and mutter my way through the Web, the trail I leave behind will reveal something about this embryonic medium.

Every Web session begins with a single click. This being a magazine devoted to innovation, I set off on my inaugural Web Crawl with a simple search on the words "innovation"and "technology,"using Alta Vista (www.altavista.digital.com). This request reaps a modest haul: "About 507,328 documents match your query,"Alta Vista tells me. Other Web users and critics have become jaded, kvetching about information overload. Not me. A half-million hits suits me fine.

Number two on the list looks promising: the "Office of Information Technology-Innovation." But my attempt to access this site yields only the rebuff that is no less aggravating for its familiarity: "Not Found: The link you followed is either outdated, inaccurate, or the server has been instructed not to let you have it." I can't count how many times I've encountered screens like this, but every time it's like a fresh insult.



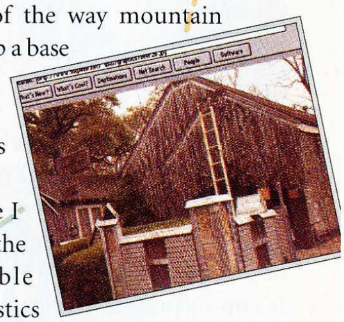
Backtracking to my list of hits (in the kind of eddying current that typifies my time on the Web), I scan past corporate brochure sites and earnest academic pages, trolling for the how-about-that nuggets that make the Web such a kick. I settle on the Irish Council for Science, Technology, and Innovation, partly for its oxymoronic ring.

Good move, it turns out. Here, at www.irsa.ie/News/Presentation/Presentation.html, I've stumbled upon that rare and precious Web beast: attractive and informative content. A lengthy article is accompanied by bold and easy-to-read graphs showing that fewer and fewer Irish students are choosing to study science. The argument runs on for 5,000 words—far more than I (and I suspect most others) would ever actually read on the screen. It doesn't help matters that the background is striped blue and yellow, with sidebar material in aqua.

I start hunting for links to allow me to exit without retreating. I have to dive all the way to the very bottom, taking the trap door to www.linkexchange.com, which delivers me to Launchbot (www.launchbot.com). LaunchBot is an annotated list of Web sites. There's no here, here—just lots of openings to a myriad of "theres." It's like walking down the midway at a carnival. I can almost hear the virtual carnies shouting out from their blue-underlined awnings, evoking aromas of greasy food. Hence my quick dive into a site devoted to barbecue (www.barbecuen.com).

One link from Launchbot seems to offer the kind of non-corporate, non-academic funkiness that shrieks: only on the Web. It's the "Ugly Lamp Contest" (www.findgreatstuff.com/uglylamp.html), and it showcases all kinds of hideous instruments of interior illumination—each with a short anecdote to justify (or apologize for) its existence. It also links other sites of similar kitschiness, including a contest to pick the "tackiest place in America," at www.thepoint.net/~usul/text/tacky.html. This photo scrapbook includes images of a 30-foot plastic lobster, a building shaped like an elephant, and (my favorite) the house covered in beer cans.

Because these photos are dead ends from a hyperlinking standpoint, I retrace my steps one more time to the mother list at Launchbot. I am using Launchbot as a kind of temporary home base on Planet Web—kind of the way mountain climbers set up a base camp from which they stage assaults on the peak.



This time I am drawn to the "Irresponsible Internet Statistics Generator," at www.ana-morph.com/docs/stats/stats. html, which squashes some of the more overheated projections of Internet growth and should be required viewing for anyone who wants to get a grip on the confusing numbers flying around about how big the Net is. Type in a date, and the site displays a patently ridiculous figure that would result if the Net is growing as fast as some formulations claim. As of May 1, I learn, the Web should comprise 113 billion sites—about 18 sites for every human alive.

That seems a fitting absurdity on which to end the journey. As is my usual pattern, I have set out with an earnest goal and then deviated from it happily in pursuit of the tantalizing distractions that the online citizenry has strewn in my path. Sometimes I feel like a puppy dog pursuing a butterfly, through a meadow bursting with scents, sights, and sounds. I occasionally catch the butterfly—but I usually gain at least as much nourishment from the chase itself.

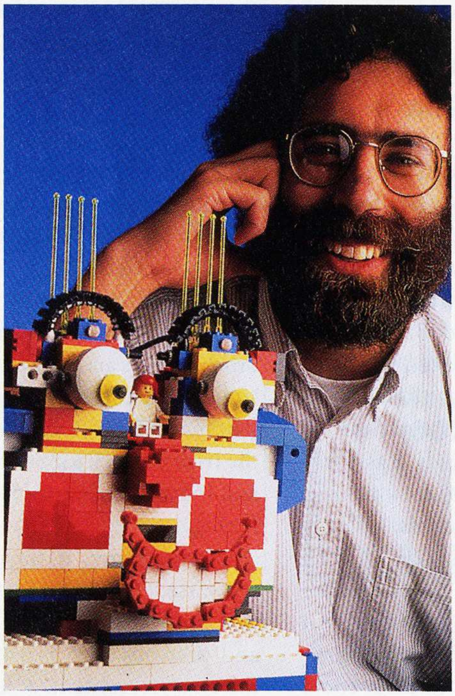
Playing Well With Others

Media Lab's Mitchel Resnick Shares His Toys

A VISIT WITH MITCHEL RESNICK IN MIT'S MEDIA LAB IS a lot like a play date. A professor in the Epistemology and Learning Group, Resnick is building teched-up toys to help kids learn in radically inventive ways. In one project, he melds tiny computers, gears, motors, and sensors with traditional Lego bricks to create what he calls "the construction kit for the digital age."

Lego's February announcement that the company will market Mindstorms (a $200 digital product based on Media Lab designs) later this year met with considerable fanfare. But Resnick is already pushing ahead with the next generation of intelligent Legos. His group is developing smaller, lighter, and—parents will be relieved to hear—cheaper versions endowed with more capabilities than the Mindstorms. A child can easily program the devices to create communicating creatures, build Rube Goldberg machines, even invent their own scientific instruments.

At the Computer Clubhouse in Boston (a learning center for disadvantaged youths that he helped found), Resnick moves easily from troubleshooting a sticky Lego gear with a fifth-grade girl to discussing the finer points of computer graphics with a budding 18-year-old artist. It's no surprise that the kids respond to Resnick. An animated talker with an almost incessant grin, he seems to understand how they think and wants to give them the tools to design, create, construct, and learn.



WEBB CHAPPELL

Man-machine interface: Resnick and Legos.

Resnick treated *TR* Associate Editor Rebecca Zacks to a game of show-and-tell, demonstrating a couple of his computerized critters.

Resnick sits in his sunny office, *a plethora of playthings spilling from between his books, papers, and computer equipment. He claims he can only talk when he has an object to fidget with, so he pulls out a new pen from a pack of 12 and begins:*

Children grow up living in the physical world. They have all types of intuitions, experiences, passions about physical objects. And there are all sorts of great things that kids learn through a manipulation of physical objects, but there are certain things that are difficult to learn.

If we give kids new types of digital building blocks, they can learn not only about number, shape, scale, but they can learn about interaction, communication, dynamics, in the same way that they traditionally learn through direct manipulation.

From a cardboard box on a shelf behind him, Resnick pulls out a pair of small Lego constructions, each equipped with four wheels and infrared sensors. He points to the miniature computers, perhaps an inch across, carried in the belly of each toy.

This is what we call a cricket; it's a type of programmable brick. This is extending the metaphor of the Lego brick and saying: What if we had a Lego brick but we put computation inside? And where traditional Lego bricks are good for building structures, these crickets are good for building behaviors. In the past, kids would build castles and houses. Now kids can build things and make them come to life.

Resnick places the toys on the floor facing away from each other.

Here's an example where we have two of these little creatures made out of crickets; these already have little programs that kids loaded into them. And at first it might look like they're not doing very much, but in fact they're both sending out signals—they communicate by infrared.

He turns the creatures around to face one another, and they begin to shimmy on their wheels.

Now if they see each other, they're so happy they go into a little dance. An important point is that we do not intend to give these as ready-made toys to kids. Because it's not when they're playing with these that we think the richest learning goes on, but in creating them, creating the structures, the mechanisms, and the behaviors. And the behaviors create the communication.

When the kids do things like this, they have to start thinking. If they want the white one to tell the red one to dance, they might first start by having the white one send the red one a signal saying "dance." But the red one might not know what "dance" means, so it won't work. Then they'll either have to teach the red one what "dance" means or have the white one communicate in the language the red one understands: It might say, "move your left wheel a little bit, move your right wheel a little bit."

As he talks, Resnick continues to demonstrate the toys' behaviors—he places his hands between them to break communication, then allows them to "see" one another again and they resume their dance.

Buried in there, there's a deep idea about communication. When I talk to you, I need a model of what you already understand. So all good communicators have a model of the listener. And as kids are designing new communicating things, they have to deal with that in a very direct way. So by building up a world of communicating things, it provides them with a framework for talking about all sorts of communication, including their own communication.

SLOAN TECHNOLOGY SERIES

"Intelligent folk, who know Flaubert's Madame Bovary and Joyce's Molly Bloom, are frustrated to be tone-deaf to the technology that has shaped their every way of life. The Sloan Technology Series provides for us all a skeleton key to understanding just how the atomic bomb and radar doomed Hitler to defeat, how the computer came to be, and x-rays evolved into cat-scans and MRIs. Romance and suspense, along with tragedy too, enliven tales of technology and science when well told."

-Paul Samuelson, Institute Professor Emeritus, Massachusetts Institute of Technology

"A great chronicle of the history of modern technology."

-Richard Preston, author of *The Hot Zone*

"Through the stories of individual technologies we can glimpse how 20th century science and technology proceeded in different fields; and through the Series as a whole, the frequently interconnected accounts help us to develop a picture of how technology has changed all our lives."

-Frank Press, President Emeritus, National Academy of Sciences

DARK SUN

The Making of the Hydrogen Bomb

Richard Rhodes

In this brilliant, riveting, major work of history, science and politics, Richard Rhodes, the Pulitzer Prize-winning author of *The Making of the Atomic Bomb,* tells for the first time the secret story of how and why the hydrogen bomb was made; traces the path by which "the Bomb," the supreme artifact of twentieth-century science and technology, became the defining issue of the Cold War; and reveals how close the world came to nuclear destruction before the United States and the former Soviet Union learned the lesson of nuclear stalemate – a stalemate, Rhodes makes clear, that forced the superpowers to tenuous truce for more than four decades, in the end bankrupting and destroying the Communist state and foreclosing world-scale war.

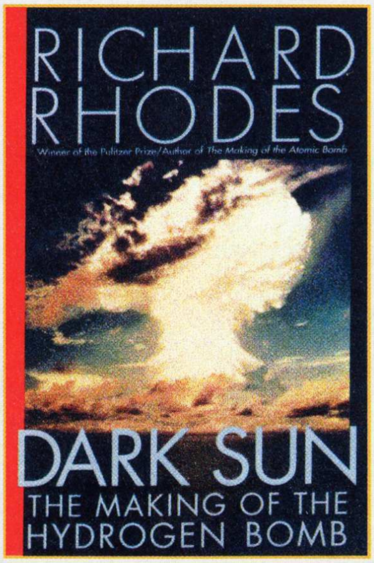
"A book of formidable range...melding previous scholarship with an abundance of fresh material...written with a sharp eye for anecdote, character and political context...brilliantly rich and vivid."

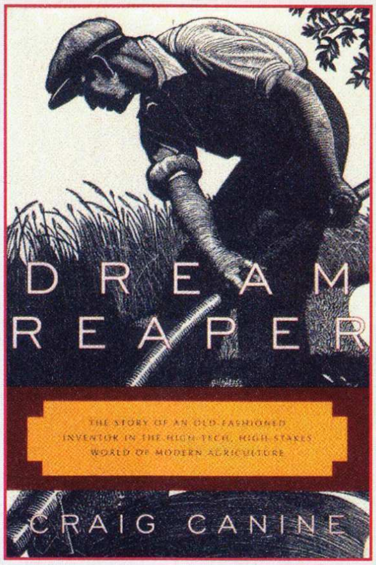
- New York Times Book Review

"Chilling and brilliant...told with gripping intensity...a view of the nuclear arms race [as] more ominous and unnerving than generally acknowledged."

-Washington Post Book World

Simon & Schuster, 1995, hardcover, #0-684-80400-X, 731 pp, $32.50
Touchstone Books, 1996, paper, #0-684-82414-0, $16.00
Simon & Schuster, audio, 1995, #0-671-52987-0, $25.00





DREAM REAPER

An Old-Fashioned Inventor in the High-Stakes World of Modern Agriculture

Craig Canine

Mark Underwood seems to be an ordinary Kansas dirt farmer. In fact he is a mechanical genius, a Thomas Edison of agriculture who has built a revolutionary new reaper that someday may change the way grain is harvested throughout the world. Mark and his cousin Ralph Lagergren, a salesman and marketing specialist, have pooled their talents to bring Mark's reaper to market. Their story illuminates America's agricultural history.

"Can a farm machine seem as vivid as a character in a story? The Bi-Rotor does, as we follow two Kansas cousins and their dream of creating the perfect harvesting machine...A remarkable story of modern farming."

-Tony Hiss, author of *All Aboard with E.M. Frimbo*

"The reader roots [for] these guys in their attempt to convince [farm-machine companies] that their strange-looking, convention-defying combine is worthy of production."

-Los Angeles Times

"Craig Canine's *Dream Reaper* is a delight. It's an important book, rich with history and stories. It brings our most essential industry – farming – into new perspective. Reading it made me want to get out a crop."

-Bobbie Ann Mason, author of *Feather Crowns*

Knopf, 1995, hardcover, #0-679-41272-7, 300 pp, $25.00
University of Chicago Press, 1997, paper, #0-226-09265-8, $17.95

A COMMOTION IN THE BLOOD

Life, Death, and the Immune System

Stephen S. Hall

We are in the midst of a quiet revolution in medicine called immunotherapy, a form of medicine that takes its lessons from the very bodies it seeks to treat. Employing the immune system's cells, its molecules, its hormones, its intricate interactions, and its exquisite timing, immunological methods are now employed to treat cancer, AIDS, chronic viral diseases, and other ailments.

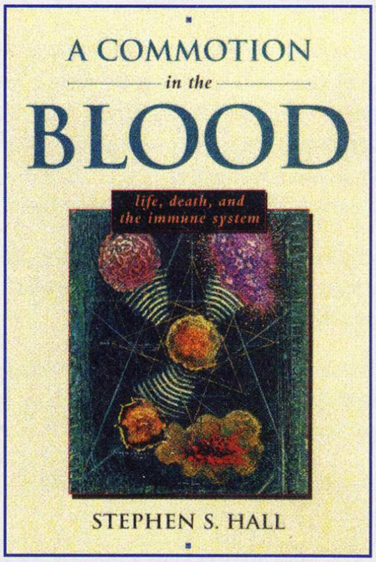
Stephen S. Hall traces the story of how doctors have learned to use the immune system and its "commotions," as one physician put it, to develop a wide array of cutting-edge therapies. Traveling between laboratory and bedside, Hall's absorbing narrative navigates the politics of discovery and explains the dazzling complexities of human blood, tracking the potent molecules and powerful cells at the heart of the immune response. Hall's earlier book, *Invisible Frontiers* has been called "the best book written about the new age of biology." Now comes this fast-paced account of medicine-in-the-making.

"A wrenching history of the peril of shopping around in the body's own pharmacy for miracle drugs." -Wayne Biddle, author of *A Field Guide to Germs*

"Hall succeeds marvelously in making science accessible to the general reader."

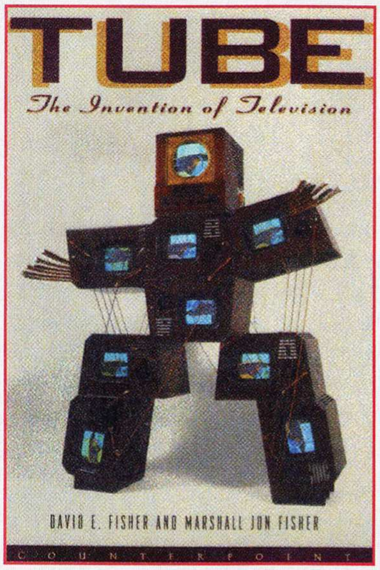
-The New York Times Book Review

Henry Holt & Co., 1997, hardcover, #0-805-03796-9, 544pp, $30.00



"I use books from the Sloan Technology Series in my own teaching. That is my highest recommendation."

-Alex Roland, Professor of History, Duke University, and former President, The Society for the History of Technology.



TUBE

The Invention of Television

David E. Fisher and Marshall Jon Fisher

In the half century since its commercial unveiling, television has become the undisputed master of communications media, revolutionizing the way postwar generations have viewed the world. Yet almost no one in America knows how television was created, who created it, or how it actually works.

The inventors of television were a diverse group of iconoclasts from different corners of the world. *Tube* traces their progress, from the laboratory prototypes that drew public laughter to the vicious courtroom battles for control of what would become an enormous market power.

"Excellent for anyone interested in the history of technology, or concerned with the management of innovation." *-New Scientist*

"The Fishers share their gift for anecdote, illuminating the greedy squabbling between RCA and a slew of competitors." *-The Boston Globe*

"An insightful look into the whole of television."
-Science News

Counterpoint, 1996, hardcover, #1-887-17817-1, 427 pp., $30.00
Harcourt Brace & Co., 1997, paper, #0-156-00536-0, $15.00

THE INVENTION THAT CHANGED THE WORLD

Radar Pioneers and their Revolution

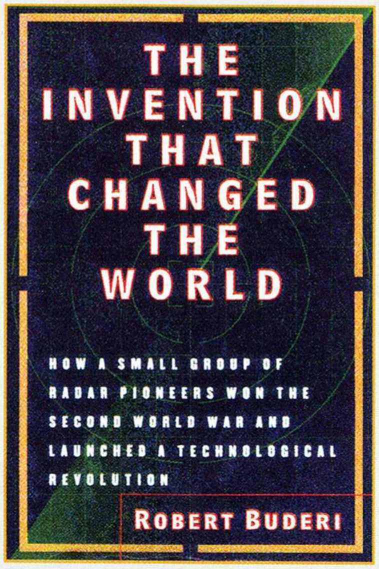
Robert Buderi

***The Invention That Changed the World* is the great and largely untold story of the colorful band of brilliant scientists who created the microwave radar systems that not only helped win World War II but set off a veritable explosion of scientific achievements and technological advances that have transformed our daily lives.**

"The boldness of the title is no exaggeration; indeed it could be lengthened to *'The Invention That Saved and Changed the World.'* Without [radar scientists in World War II], Britain would have gone down. Buderi tells their story with skill, power, and insight – and best of all in language that makes their work understandable to a lay audience. Highly recommended." -Stephen Ambrose, author of *D-Day* and *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West*

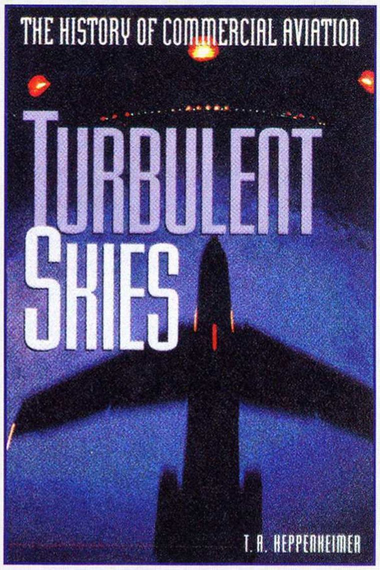
"[This] is a technological thriller better than Tom Clancy's best." -Richard Rhodes, author of *The Making of the Atomic Bomb* and *Dark Sun: The Making of the Hydrogen Bomb*

Simon & Schuster, 1996, hardcover, #0-684-81021-2, 575 pp., $30.00
Touchstone Books, 1998, paper, #0-684-83529-0, $16.00



"These volumes speak eloquently about stories fundamental to the history of this century."

-Robert Cook-Deegan, M.D., Director, National Cancer Policy Board, Institute of Medicine and Commission on Life Sciences, National Academy of Sciences



TURBULENT SKIES

The History of Commercial Aviation

Thomas A. Heppenheimer

Chronicling the meteoric rise of commercial aviation, *Turbulent Skies* is a riveting, multifaceted tale of daredevils and innovators, of the power and pitfalls of big business, and of the awe-inspiring achievements of modern technology. Charting a course marked by both spectacular successes and dramatic failures, the book follows the intense competition to create bigger, better, faster planes and to revolutionize air travel.

"An important addition to the history of technology as well as business, Heppenheimer is as gifted at explaining the development of the jet engine as he is at tracing the rise and triumph of the aircraft industry over ground transport."
-Publisher's Weekly

"Not only is his analysis insightful, but his obvious understanding and clear explanation of the impact made by various technological advances add a dimension to this book that others on the topic do not have."
-Booklist

"With the precision of a scientist, a good reporter's marshaling of disparate facts, and the vigor of a natural storyteller, Heppenheimer offers an absorbing narrative."
-Richard Snow, Editor, *American Heritage*

John Wiley & Sons, 1995, hardcover, #0-471-10961-4, 388 pp, $30.00
John Wiley & Sons, 1998, paper, #0-471-19694-0, $18.95

NAKED TO THE BONE

Medical Imaging in the 20th Century

Bettyann Holtzmann Kevles

X-rays, fluoroscopy, ultrasound, CT, MRI, and PET scans – medical imaging has become a familiar part of modern health care today. In this lively history of medical imaging, the first to cover the full scope of the field from X-rays to MRI-assisted surgery, Bettyann Kevles explores the consequences of these developments for medicine and society. Through lucid prose, vivid anecdotes, and more than seventy striking illustrations, she shows how medical imaging has transformed the practice of medicine. Beyond medicine, they helped undermine Victorian sexual sensibilities, gave courts new forensic tools, provided plots for novels and movies, and offered artists from Picasso to Warhol new ways to depict the human form.

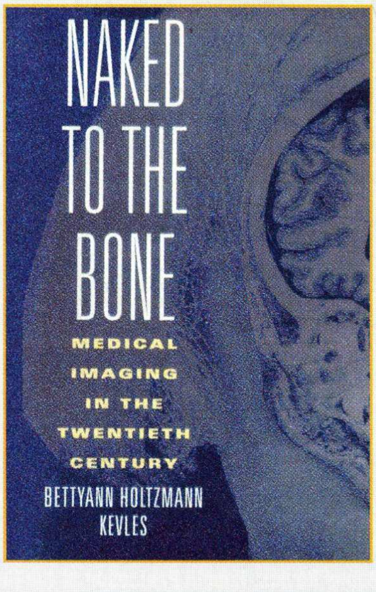
"A real eye-opener of a book! Not merely highly original, *Naked to the Bone* offers wonderful proof that medicine, art, society, and the body all form part of a continuum. Bettyann Holtzmann Kevles combines technical mastery with stylistic flair to make this one of the most exciting books of the year."

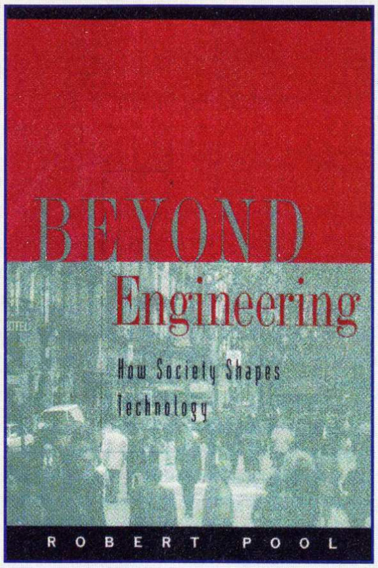
-Roy Porter, Professor of the Social History of Medicine, Wellcome Institute for the History of Medicine, London

"This fascinating book will be of interest to patients, health care workers, and anyone else who has ever contemplated images of the inside of the human body."

-Joel D. Howell, M.D., Ph.D., Department of Internal Medicine and of History, University of Michigan, and author of *Technology in the Hospitals: Transforming Patient Care in the Early Twentieth Century*

Rutgers University Press, 1996, hardcover, #0-813-52358-3, 378pp, $32.36





BEYOND ENGINEEERING

How Society Shapes Technology

Robert Pool

Every now and then a book comes along to reshape completely how people think about a subject. *Beyond Engineering* is such a book. If you look closely at the history of any invention, says its author, you will find that factors unrelated to engineering – historical, political, cultural, organizational, economic, and psychological – all influence the path a technology takes. This is an illuminating account of how technology and the modern world shape each other.

"Like all great storytellers, Pool weaves his entertaining narrative into an exploration of some deeply serious questions. [He] treats the reader to 101 tales about the creation and use of modern technologies [and] illuminates critical questions in a way that should bring insight to non-technical and to many technical readers."

-Professor M. Granger Morgan, Head of the Department of Engineering and Public Policy, Carnegie Mellon University

"For anyone at all interested in understanding the complex and puzzling ways in which major new technologies came to be and ended up as they have, [this book] is not to be missed."

-Robert K, Merton, Professor Emeritus, Columbia University

"The best book available for the general reader engaging our human-built world."

-Thomas P. Hughes, Mellon Professor Emeritus, The University of Pennsylvania, and Distinguished Visiting Professor, Massachusetts Institute of Technology

Oxford University Press, 1997, hardcover, #0-195-10772-1, 358 pp, $30.00

COMPUTER

A History of the Information Machine

Martin Campbell-Kelly and William Aspray

Earlier histories of the computer depict it as a tool created by and for scientists. This book shows how business and government were the first to explore the unlimited potential of the machine as an information processor. Here is a tale of old-fashioned entrepreneurship in a symbiotic relationship with scientific know-how. It is the story of how the computer has reshaped our society. Filled with lively insights and a strong narrative, here is a book no owner or user of computers can miss.

"A very important book. Essential reading for those who are curious about the 'computer revolution' or have to live with or exploit this technology."

-James W. Cortada, author of *Before the Computer* and Sr. Consultant, IBM

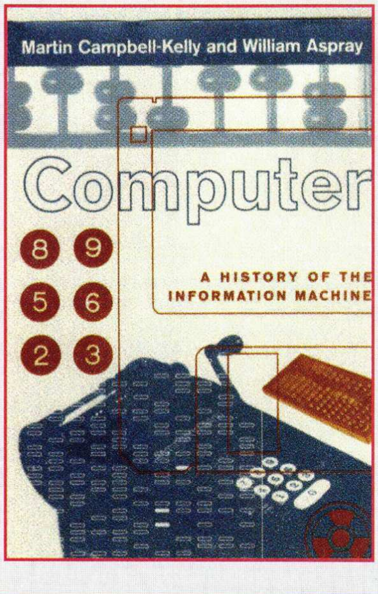
"A remarkable guide to the information age, introducing the main features of today's computers and their uses one by one. By placing the design and use of computers in a historical perspective, the authors have produced a splendid primer for our times."

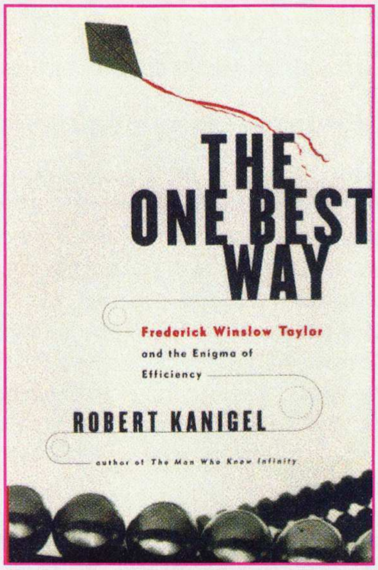
-I. Bernard Cohen, Victor S. Thomas Professor of the History of Science, Emeritus, Harvard University

"Well organized and easy to read, this fascinating account should appeal to anyone interested in the history of computers and the information processing industry. The balanced treatment of events in the United States and Great Britain is particularly noteworthy."

-Emerson Pugh, author of *Building IBM: Shaping an Industry and Its Technology*

Basic Books, 1996, hardcover, #0-465-02989-2, 342 pp., $28.00
Basic Books, 1997, paper, #0-465-02990-6, $15.00





THE ONE BEST WAY

Frederick Winslow Taylor and the Enigma of Efficiency

Robert Kanigel

Frederick Winslow Taylor, the first efficiency expert and model for all the stopwatch-clicking engineers who stalk the factories and offices of the industrial world, influenced Ford's assembly line and Lenin's Soviet Russia. His ceaseless quest for "the one best way" changed the very texture of twentieth-century life.

Robert Kanigel's epochal biography recounts the life of the man who taught us *not* to stop and smell the roses, and whose compulsions eerily foreshadowed how we live and work today.

"Frederick Taylor's zealous determination to make efficiency the prime temporal value of our century has had untold consequences for civilization. Kanigel's intimate account of Taylor's personal odyssey and mission holds up a revealing mirror to our life and times." -Jeremy Rifkin, author of *The End of Work* and *Time Wars*

"What is so extraordinary about Robert Kanigel's *The One Best Way* is that it's fair to Frederick Taylor, fair to those he Taylorized in his own lifetime, and fair to the millions (me included), who've chafed against Taylorism for over a century now." -Barbara Garson, author of *All the Livelong* Day and *The Electronic Sweatshop*

"This steam-powered trip through the Iron Age of America, where an idealistic craftsman becomes a huckster for efficiency, is a delightful read. The writing sings with a love for yesterday's technology, teaching lessons yet to be learned by today's software developers." -Clifford Stoll, author of *The Cuckoo's Egg* and *Silicon Snake Oil*

Viking Press, 1997, hardcover, #0-670-86402-1, 675pp, $34.95

CRYSTAL FIRE

The Birth of the Information Age

Michael Riordan and Lillian Hoddeson

On December 16, 1947, John Bardeen and Walter Brattain, physicists at Bell Laboratories, jabbed two electrodes into a sliver of germanium half an inch long. The electrical power coming out of that piece of germanium was 100 times stronger than what went in. In that moment the transistor was invented and the information age began.

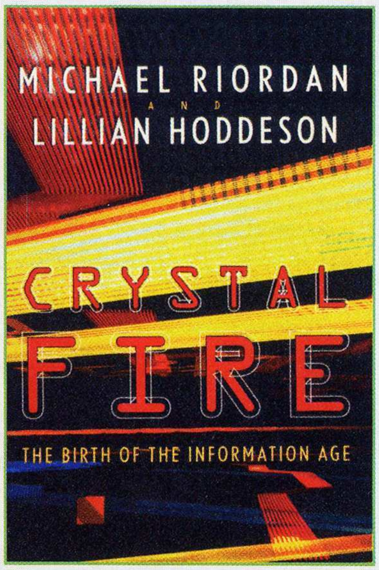
Crystal Fire is a tale of human factors in technology – the pride and jealousies coupled with scientific and economic aspiration that led to the creation of modern microelectronics and ignited the greatest technological explosion in history.

"A swiftly moving narrative account of the remarkable people who invented the transistor – and thereby created today's Information Age." -Charles C. Mann, co-author of *@Large: The Strange Tale of the Internet's Greatest Invasion*

"Clear, readable, interesting, deeply knowledgeable – an important subject and a damn fine book." -Horace Freeland Judson, director, Center for History of Recent Science, George Washington University

"Tracing the elusive trail of scientific and engineering genius through a corporate maze of collective research and development, *Crystal Fire* provides a probing analysis and sparkling insights into our remarkable era of technological achievement." -Thomas P. Hughes, Mellon Professor Emeritus, The University of Pennsylvania and Distinguished Visiting Professor, Massachusetts Institute of Technology

W.W. Norton & Co., 1997, hardcover, #0-393-04124-7, 352 pp, $27.50



"Invaluable for students of the history of science and technology as well as for students preparing for careers in engineering or applied science."

Albert Bowker, Chancellor Emeritus, University of California, Berkeley, and City University of New Yo

In 1998:

INSISTING ON THE IMPOSSIBLE
The Life of Edwin Land
by Victor McElheny

VISIONS OF TECHNOLOGY
A Century of Provocative Readings
Edited by Richard Rhodes

In 1999:

CITY OF LIGHT
The Story of Fiberoptics
by Jeff Hecht

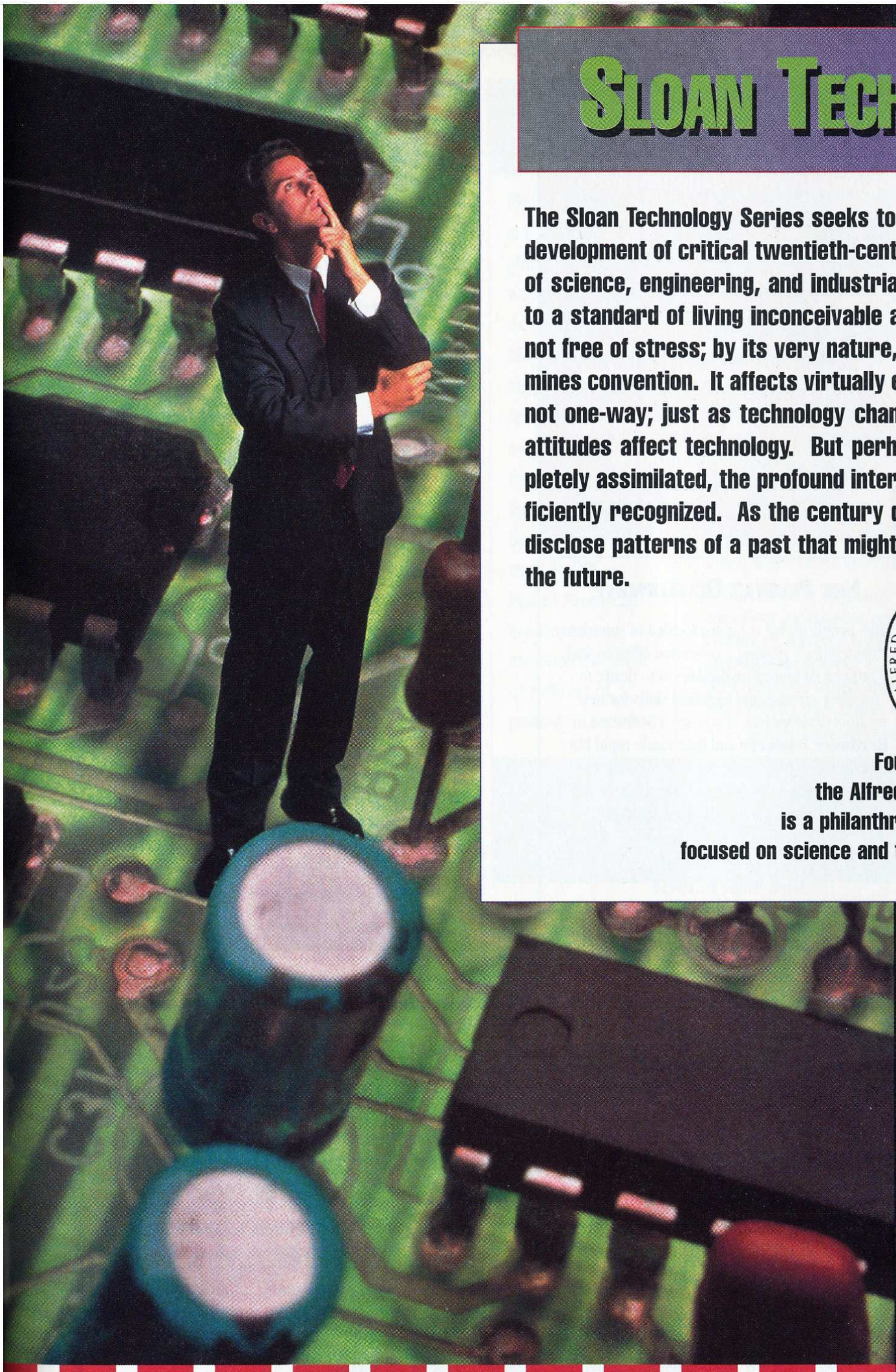
THE LAST BIG COOKIE
An inside account of the first race to space with commercial goals.
by Gary Dorsey

In 2000:

...still more to come!

"The Sloan Technology Series is a tour de force, a unique collection of absorbing and richly informative volumes about the technologies that have transformed our lives. These Sloan books are a feast for the reader, and indispensable to anyone concerned with the shaping of the twentieth century."

-Daniel Kevles, Koepfli Professor of the Humanitie California Institute of Technology



Sloan Technology Series

The Sloan Technology Series seeks to present to the general reader the story of the development of critical twentieth-century technologies. Technology — the application of science, engineering, and industrial organization — has led, in developed nations, to a standard of living inconceivable a hundred years ago. The process, however, is not free of stress; by its very nature, technology brings change in society and undermines convention. It affects virtually every aspect of human endeavor. The effects are not one-way; just as technology changes society, so too do societal structures and attitudes affect technology. But perhaps because technology is so rapidly and completely assimilated, the profound interplay of technology and society has not been sufficiently recognized. As the century draws to an end, it is hoped that the Series will disclose patterns of a past that might provide perspective on the present and inform the future.

ALFRED P. SLOAN FOUNDATION
1934

**Founded In 1934,
the Alfred P. Sloan Foundation
is a philanthropic nonprofit institution
focused on science and technology and economic progress.**

"This Series makes an important contribution to the understanding of the history and current status of technology in the world. It offers valuable insights to business, government and academia. Through these books, the Sloan Foundation continues to play its distinctive role in enhancing public appreciation of technology."

-William Spencer, Chairman of the Board, SEMATECH

BAKER & TAYLOR
Information and Entertainment Services

PUBLIC LIBRARIES:	ACADEMIC LIBRARIES:
MAIL ORDERS:	
Baker & Taylor Books	Baker & Taylor Books
251 Mt. Olive Church Road	501 S. Gladiolus
Commerce, GA 30599-1100	Momence, IL 60954-1799
Attn: Order Department	Attn: Order Department

PHONE ORDERS:	1-800-775-1100	1-800-775-2300
FAX ORDERS:	1-800-775-7480	1-800-775-3500
ELECTRONIC ORDERS:	1-800-775-0410	1-800-775-0410

SINGLES IN SCIENCE

and others interested in science/nature are meeting through *Science Connection*

1-800-667-5179; sciconnect@compuserve.com
On-line registration: www.sciconnect.com/

NEW AUTHORS
PUBLISH YOUR WORK
ALL SUBJECTS CONSIDERED
Fiction, Biography, Religious, Poetry, Children's.
AUTHORS WORLDWIDE INVITED.
WRITE OR SEND YOUR MANUSCRIPT TO
MINERVA PRESS
2 OLD BROMPTON ROAD, LONDON SW7 3DQ, ENGLAND

RAISE MONEY ON WALL ST.

Private Placements, IPOs, Bridges, PIPEs
No Startups
Larry Kunstadt, PhD
Acadia Financial, LLC
914-674-2287

Date someone in your own league.

Graduates and faculty of MIT, the Ivies and Seven Sisters meet alumni and academics.

The Right Stuff.
1-800-988-5288

A BETTER MOUSETRAP!

MIT-Educated technologists will invent it for you.
(781) 862-0200 www.weinvent.com

CAREERS ADVERTISING

For rates and information on advertising in the Careers section contact:

Charles Dupree
Tel: 404-303-0179
Fax: 404-303-5124
cdupree@mindspring.com
http://web.mit.edu/techreview

RATES: $35 per line, 3-line minimum. (One line equals approximately 50 characters.)

NEW PRODUCT DEVELOPMENT

High profile global company located in suburban Philadelphia is making a concerted effort to find and groom innovative thinkers who desire to use their creative and technical skills for new product development. If you are a **Software** or **Hardware Engineer** and have made rapid but unsatisfactory progress in your current situation contact Amy @ WAI for more info on how you can be part of this dynamic environment.

(215)822-6411 x 19 or
1501 Lower State Rd.
North Wales, PA 19454
Fax: (215) 997-1634

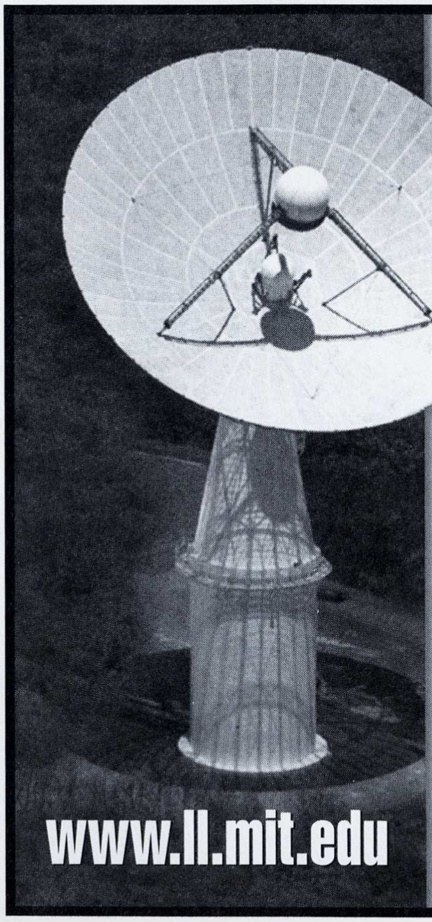
Information Technology & Management Consulting

We are a fast-growing firm that combines IT and Management Consulting. If *you*...

- Understand the power of IT, and want to apply it to business problem solving
- Have graduated from a top academic program (Masters or PhD preferred)
- Can visualize complex systems
- Have 3+ years of experience in project management
- Are looking for a fresh, fast-moving company with exceptional opportunities

We invite you to find out more about us:

PRINCETON CONSULTANTS
www.princeton.com



THE OPPORTUNITY OF A LIFETIME

Imagine working at a place where the discoveries of research are transferred directly into the development of real-world applications, such as air defense, space surveillance, communications and air traffic control systems. An environment of vast resources where the advancement of technology and one's intelligence are highly valued. You might call it the opportunity of a lifetime – we call it MIT Lincoln Laboratory.

If you are pursuing a degree in:

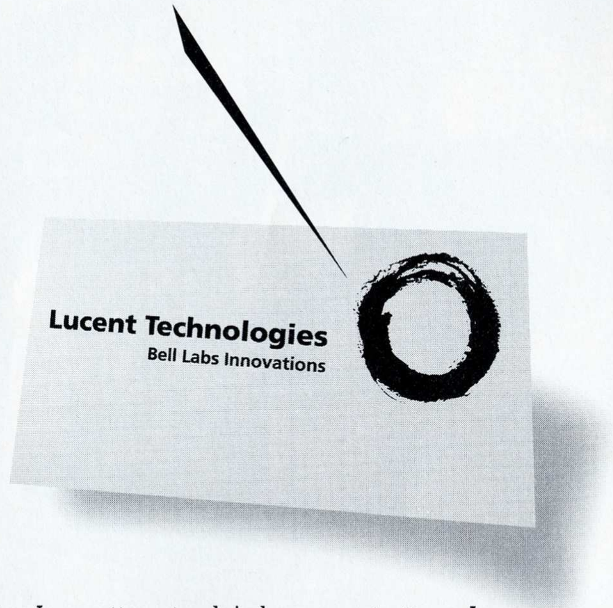
Electrical Engineering
Physics
Mathematics
Computer Science

we want to talk to ***you.***

Office of Human Resources, MIT Lincoln Laboratory, Box MIT1, 244 Wood Street, Lexington, MA 02173-9108. Fax: (781) 981-7086.
Equal Opportunity Employer, M/F/D/V., U.S. Citizenship Required .

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

are **you** our next innovator?



Innovation. It's our business at Lucent Technologies. Innovations in global communications. Innovations in engineering and software development. Innovative strategies in marketing, sales, and business. The list goes on.

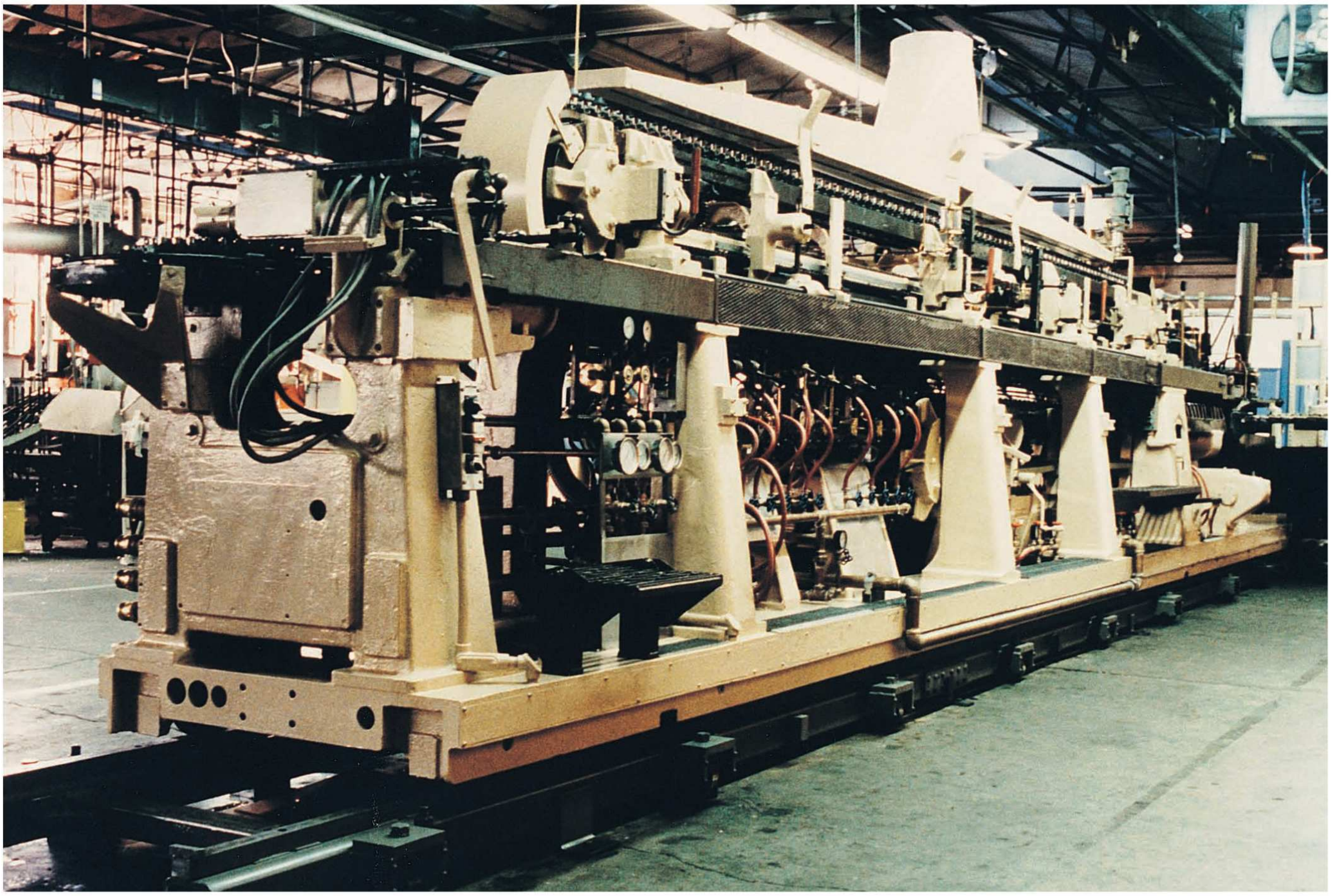
At Lucent, we're creating the next generation of telecommunications today with one breakthrough after another. From the first transistor to the latest Internet technology, our history of Bell Labs innovations continues at full speed. And you could be our next innovator.

Currently, we have opportunities available throughout our organization for:

- Security Consultants
- Security Engineers
- Project Managers
- Sales Account Executives
- Software Developers
- Process Engineers
- Test Engineers
- Assembly/Packaging Engineers
- ASIC Design Engineers
- Software Integration Test Engineers
- SONET/SDH Digital ASIC Design Engineers
- DSP Engineers
- SAP R/3 Specialists
- Marketing Managers
- Market Analysts
- Systems Analysts
- Failure Analysis Engineers
- Mechanical Engineers
- Design Engineers
- Firmware Design Engineers
- Serviceability Engineers
- RF Engineers
- Systems Architects
- Telecommunications Technicians

Come experience the Information Revolution firsthand. Send your resume to: Lucent Technologies, attn: Employment Manager, Dept. MIT/4001/97, 283 King George Road, Room B2C76, Warren, NJ 07059. Or apply on-line at www.lucent.com   Lucent is an equal opportunity employer.

We make the things that make communications work.™



COURTESY OF OSRAM SYLVANIA INC.

Building Edison's Bulb

The Corning Ribbon Machine brought electric light to life

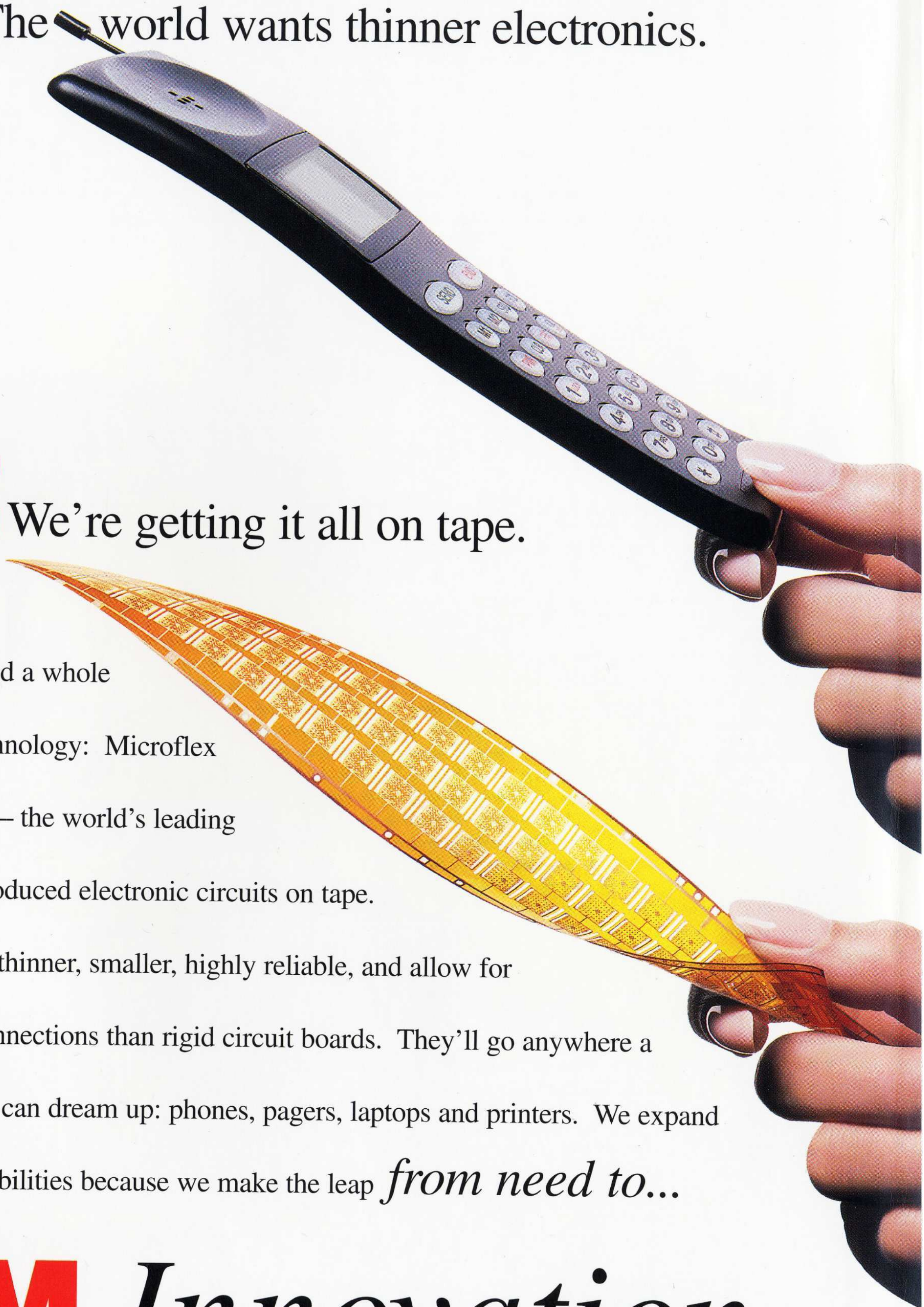
EDISON GETS CREDIT FOR INVENTING THE INCANDESCENT light bulb, but few of us would own one were it not for the Corning Ribbon Machine. For more than 70 years, this machine and its successors have churned out the bulbous glass shells that house fragile filaments. Not the most glamorous of tasks, but by performing it cheaply and quickly this machine revolutionized an industry and, ultimately, helped light our world.

For years after Edison built the first electric light bulb in 1879, his favorite invention served only as a laboratory device. Large-scale manufacture of Edison's contraption was impossible because the glass had to be blown by hand—a time-consuming and prohibitively expensive process. Though glass companies spent decades of research and development to automate the process, progress was disappointingly slow. Then, in 1926, Corning Glass Works introduced the Ribbon Machine and put an end to the bulb production problem. Today, modern versions of the machine make more than 2 billion glass shells each year. A mere 15 ribbon machines would be enough to fill the entire world's need for regular-sized incandescent bulbs and ensure that, wherever electricity flows, there can be light.

The machine's design is ingenious. A melting tank above one end feeds a continuous stream of molten glass down between two water-cooled steel cylinders. The cylinders rotate and flatten the glass into a ribbon—only one-eighth of an inch thick—extruded onto a horizontal metal conveyor belt. Still about 1100 C, the glass begins to fall through regularly spaced holes in the belt. Then plungers drop onto the ribbon from above and blast pressurized air into each sagging bulge, forcing it to expand. At the same time, rotating split molds below the conveyor belt briefly clamp together around the forming bulbs, ensuring the proper size and shape. Finally, a small metal tool breaks each newly formed bulb from the ribbon, and the excess glass is fed back into the melting tank. TR

Technology Review welcomes suggestions from readers for Trailing Edge. If yours is selected, you will win a year's subscription to *TR*. This month's winner is Burton Baker, a retired patent attorney in St. Joseph, Mich. Send your suggestions to: Trailing Edge, *Technology Review*, MIT Building W59, Cambridge MA 02139 or e-mail TR-trailingedge@mit.edu.

1 The world wants thinner electronics.



2 We're getting it all on tape.

3M has pioneered a whole new technology: Microflex Circuits – the world's leading mass-produced electronic circuits on tape. They're thinner, smaller, highly reliable, and allow for more connections than rigid circuit boards. They'll go anywhere a designer can dream up: phones, pagers, laptops and printers. We expand the possibilities because we make the leap *from need to...*

3M *Innovation*

For more information, call 1-800-3M-HELPS, or Internet: http://www.mmm.com